PROCEEDINGS

OF THE

NATIONAL INSTITUTE OF SCIENCES OF INDIA

VOL. V

1939

CALCUTTA:

PUBLISHED BY THE NATIONAL INSTITUTE OF SCIENCES OF INDIA

CONTENTS

No. 1—*May*, 1939.

No. 2—*July*, 1939.

CONTENTS

No. 3—*December*, 1939.

Fourth Annual General Meeting.

The Fourth Annual General Meeting of the National Institute of Sciences of India was held at 5 P.M. on Monday, the 2nd January, 1939, in the Hailey Hall, Lahore.

The following Fellows were present:—

Prof. S. S. Bhatnagar, *Vice-President*, in the chair.
Prof. S. P. Agharkar, *Honorary Secretary*.

Prof. R. Gopala Aiyar.
Prof. Y. Bharadwaja.
Dr. B. L. Bhatia.
Dr. N. K. Bose.
Dr. H. Chaudhuri.
Dr. B. N. Chopra.
Prof. S. C. Dhar.
Prof. S. L. Ghose.
Prof. J. C. Ghosh.
Khan Bahadur M. Afzal Husain.
Dr. A. C. Joshi.
Dr. S. N. Kapur.
Prof. P. K. Kichlu.
Dr. D. S. Kothari.
Dr. H. R. Mehra.
Prof. S. K. Mitra.
Principal P. Parija.
Dr. B. Prashad.
Dr. H. K. Sen.
Principal J. M. Sen.
Prof. M. R. Siddiqi.
Prof. B. K. Singh.

The meeting was also attended by about 40 visitors.

1. The minutes of the Tenth Ordinary General Meeting were read and confirmed.

2. The Chairman appointed Dr. N. K. Bose and Dr. H. Chaudhuri to act as scrutineers of the ballot papers received for the election of officers and other members of the Council for the year 1939.

3. The Chairman appointed Dr. B. Prashad and Prof. B. K. Singh to act as scrutineers of the voting papers received for the election of Brigadier C. G. Lewis as an Ordinary Fellow under Regulation 12 regarding the election of Ordinary Fellows. On the votes received Brigadier Lewis was elected a Fellow.

4. The following Ordinary Fellows were admitted as Fellows as per Rule 13 :—

Dr. N. K. Bose.
Prof. S. C. Dhar.
Prof. R. Gopala Aiyar.
Dr. A. C. Joshi.

5. The following were declared to have been elected officers and other members of the Council for the year 1939 :—

President: Brevet-Col. R. N. Chopra.
Vice-Presidents: Sir U. N. Brahmachari.
Dr. A. M. Heron.
Treasurer: Dr. B. S. Guha.
Foreign Secretary: Prof. B. Sahni.
Secretaries: Prof. S. P. Agharkar.
Dr. C. S. Fox.

Members of Council: Prof. S. S. Bhatnagar, Mr. H. G. Champion, Prof. J. C. Ghosh, Khan Bahadur M. Afzal Husain, Dr. M. S. Krishnan, Dr. R. B. Lal, Prof. S. K. Mitra, Prof. J. N. Mukherjee, Dr. C. W. B. Normand, Prof. G. R. Paranjpe, Dr. B. Prashad, Prof. M. Quroshi, Rao Bahadur G. N. Rangaswami Ayyangar, Prof. N. R. Sen, Sir Shah M. Sulaiman, Col. J. Taylor, Rao Bahadur B. Venkatesachar and Mr. F. Ware.

6. Mr. L. Mason was proposed for election as an Ordinary Fellow of the National Institute under Regulation 12 regarding the election of Ordinary Fellows.

7. The Annual Report for the year 1938, prepared by the Council, was adopted.

8. Owing to the absence of the President, Prof. M. N. Saha, on account of illness, his Annual Address on the 'Solar Control of the Atmosphere' was read on his behalf by Prof. S. K. Mitra.

9. The following papers were read:—

(1) Amplification of the theory of multiphased gastrulation among insects, and its applicability to some other Arthropods. By M. L. Roonwal. (Communicated by Prof. K. N. Bahl.)

(2) Heat of Ionic dissociation of Iodides of rubidium and lithium and electron affinity of Iodine. By B. N. Srivastava. (Communicated by Prof. M. N. Saha.)

With a vote of thanks to the Chair the meeting terminated.

National Institute of Sciences of India

ANNUAL REPORT

The Council of the National Institute of Sciences of India have pleasure in submitting the following report on the general concerns of the Institute for the year 1938, as required by the provisions of rule 48(*f*).

Membership.

The number of Fellows on the roll of the Institute at the beginning of the year was 151 Ordinary Fellows and 13 Honorary Fellows. 10 Ordinary Fellows and 4 Honorary Fellows were elected during the year in accordance with the procedure laid down in the Regulations. 4 Ordinary Fellows resigned their Fellowship during the year. The total number of Fellows on the roll at the end of the year is 157 Ordinary and 17 Honorary Fellows. Of the 157 Ordinary Fellows 5 are non-resident.

Meetings.

The Third Annual Meeting was held at the Senate House, Calcutta University, on the 8th January, 1938. An account of the meeting was published in the *Proceedings*, Vol. IV, pp. 1-2.

Three Ordinary General Meetings were held during the year, the first on the 25th and 26th July, 1938 in the Library Hall of the Indian Meteorological Department, Poona, the second on the 20th August, 1938 in the rooms of the Royal Asiatic Society of Bengal, Calcutta, and the third on the 26th and 27th September, 1938 at the Royal Institute of Science and the Sir Cowasji Jehangir Hall, Bombay. Accounts of these meetings, together with the papers read, are being published in the *Proceedings*. The first of these meetings included a Symposium on 'Weather Prediction' and the third held on September 26th and 27th a Symposium on the 'Recent Work on the Synthesis of naturally occurring substances' as well as three public lectures given by scientists.

The Council.

The officers and members of Council for the year 1938 were elected at the Third Annual Meeting held on the 8th January, 1938. The Council, together with the representatives of the co-operating Academies, the Indian Science Congress Association and the Government of India, was constituted as follows:—

President	Prof. M. N. Saha.
Vice-Presidents	Prof. S. S. Bhatnagar. Brevet-Col. R. N. Chopra.

Additional Vice-Presidents ..	Sir U. N. Brahmachari. Prof. N. R. Dhar. Rao Bahadur T. S. Venkataraman. Dr. T. S. Wheeler.
Treasurer	Dr. B. S. Guha.
Foreign Secretary	Prof. B. Sahni.
Secretaries	Prof. S. P. Agharkar. Dr. A. M. Heron.
Members of Council ..	Mr. T. P. Bhaskara Shastri. Dr. G. S. Bose. Mr. H. G. Champion. Prof. J. C. Ghosh. Dr. F. H. Gravely. Khan Bahadur M. Afzal Husain. Dr. K. S. Krishnan. Dr. R. B. Lal. Prof. S. K. Mitra. Prof. J. N. Mukherjee. Dr. C. W. B. Normand. Sir Arthur Olver. Dr. Baini Prashad. Prof. N. R. Sen. Lt.-Col. S. S. Sokhey. Prof. V. Subrahmanyan. Col. J. Taylor. Rao Bahadur B. Venkatesachar. Brigadier Sir Harold Couchman } *(Ex-officio.)* Sir Lewis Fermor. }
Additional Members of Council ..	Sir Bryce Burt. Prof. P. S. MacMahon. Prof. G. Matthai. Mr. W. D. West.

Dr. S. B. Dutt was appointed an additional member of Council in place of Prof. P. S. MacMahon who had left India.

The Council held eight meetings during the year.

Additional Committees.

A sub-committee consisting of (*a*) the General Secretaries, (*b*) the Editor, (*c*) Prof. J. N. Mukherjee and (*d*) Prof. S. K. Mitra was appointed to draw up general rules regarding Symposia.

A sub-committee consisting of the President, the Secretaries and the Editor was appointed to draft rules regarding the refereeing of papers submitted for publication by the Institute.

A sub-committee consisting of the President, the Secretaries, the Treasurer and Dr. Baini Prashad was appointed to propose suitable modifications in the rules of the Institute to make provision for the association of eminent personages with the National Institute.

Publications.

Four numbers of the *Proceedings* and one number of the *Transactions* were published during the year.

Dr. M. S. Krishnan was appointed joint editor of the publications of the Institute.

Exchanges.

Five additional Societies and Institutions have been placed on the exchange list for the publications of the Institute, bringing the total number on the list to eighty-five (*vide* Appendix IV).

Library.

Four hundred and seventy-two books and parts of periodicals and reprints were added to the library during the year (*vide* Appendix V).

A noteworthy addition to the library was a complete set, as far as published, of the Reports of the Canadian Arctic Expedition, 1913–1918, received from the Canadian Department of Mines, Ottawa.

Presents and Donations.

The following grants-in-aid have been sanctioned during the year to the Institute:—

(1) Rs.200 per annum for two years from the session 1937-38 from the Dacca University.

(2) Rs.500 for the session 1938-39 from the Calcutta University.

(3) Rs.300 for the year 1347 F. from Osmania University.

(4) Rs.500 per annum for three years from 1938-39 from the Imperial Council of Agricultural Research.

Finance.

An audited statement of accounts of the National Institute for the period from 1st December, 1937 to 30th November, 1938 is submitted (*vide* Appendix VI). The total ordinary receipts for this period are Rs.19,602-3-3, inclusive of grants-in-aid (from the Government of India for 1937-38 and 1938-39, Rs.12,000-0-0 and from Universities, Rs.500-0-0), and the ordinary payments, Rs.8,787-8-3, leaving a balance of Rs.10,814-11-0. A sum of Rs.512-0-0 was realized on account of admission fees and Rs.50-14-0 as donation.

At the beginning of the year the cash position of the Institute was as follows:—

	Rs.	A.	P.
In Savings Bank account	2,089	9	0
,, Government paper	33,000	0	0
,, Current account	700	15	5
,, hand	8	0	0
TOTAL ..	35,798	8	5

At the end of the year, however, the cash position of the Institute was as follows:—

	Rs.	A.	P.
In Savings Bank account	2,145	2	0
,, Government paper	33,000	0	0
,, Current account	12,023	15	8
,, hand	6	15	9
TOTAL ..	47,176	1	5

APPENDICES.

I. List of Fellows.
II. Abstracts of Proceedings of the Council.
III. Committees, 1939.
IV. List of Institutions on the Exchange List.
V. Periodicals received for the library.
VI. Audited statement of accounts, December 1937—November 1938.
VII. Budget Estimate, December 1938—November 1939.

APPENDIX I

LIST OF FELLOWS

ORDINARY FELLOWS

1. ABRAHAM, LT.-COL. W. E. V., A.R.C.S. (I.), F.G.S., M.Inst.P.T., Senior Geologist, Burmah Oil Co., Ltd., Burma, Khodaung, Magwe, Burma. (1936).
2. AGHARKAR, S. P., M.A., Ph.D., F.L.S., Ghose Professor of Botany, Calcutta University, 35, Ballyganj Circular Road, Calcutta.
3. AHMAD, NAZIR, O.B.E., M.Sc., Ph.D., Director, Indian Central Cotton Committee's Technological Laboratory, Matunga, Bombay.
4. AIYAR, R. GOPALA, M.A., L.T., M.Sc., University Professor of Zoology, and Director, University Zoological Laboratory, Madras. (1938).
5. AJREKAR, S. L., B.A., I.E.S. (Retd.), 855, Bhamburda, Poona 4.
6. ANANDA RAO, K., Rao Bahadur, M.A., I.E.S., Professor of Mathematics, Presidency College, Madras.
7. ASH, W. C., B.Sc., M.Inst.C.E., A.M.I.Mech.E., Bengal Club, Calcutta.
8. AUDEN, J. B., M.A. (Cantab.), Geologist, Geological Survey of India, Indian Museum, Calcutta. (1938).
9. AWATI, P. R., B.A., D.I.C., I.E.S., Professor of Zoology, Royal Institute of Science, Mayo Road, Bombay 1.
10. BAGCHEE, K. D., D.Sc., D.I.C., Mycologist, Imperial Forest Research Institute, Dehra Dun, U.P.
11. BAHL, K. N., D.Sc., D.Phil., Professor of Zoology, Lucknow University, Lucknow.
12. BANERJI, A. C., M.Sc., M.A., F.R.A.S., I.E.S., Professor of Mathematics, Allahabad University, Allahabad.
13. BANERJI, S. K., D.Sc., Meteorologist, Meteorological Office, Poona 5.
14. BEESON, C. F. C., D.Sc., Forest Entomologist, Imperial Institute of Forest Research, Dehra Dun, U.P.
15. BHARADWAJA, Y., M.Sc., Ph.D. (Lond.), F.L.S., Professor of Botany and Head of the Department, Hindu University, Benares. (1937).
16. BHASKARA SHASTRI, T. P., M.A., F.R.A.S., Director, Nizamiah Observatory, Hyderabad (Deccan).
17. BHATIA, B. L., D.Sc., F.Z.S., F.R.M.S., F.A.Sc., Director, The Science Press of India, 13, Hotusingh Road, Lahore. (1937).
18. BHATNAGAR, S. S., O.B.E., D.Sc., Professor of Chemistry and Director, University Chemical Laboratories, Punjab University, Lahore.
19. BHATTACHARYA, D. R., M.Sc., Ph.D., Dr. ès Sciences (Paris), Professor of Zoology, Allahabad University, 7, Malaviya Road, Allahabad.
20. BOMFORD, MAJOR GUY, R.E., Survey of India, Dehra Dun. (1935).
21. BOSE, D. M., M.A., B.Sc., Ph.D., Director, Bose Institute, 93, Upper Circular Road, Calcutta.
22. BOSE, G. S., D.Sc., M.B., Head of the Department of Experimental Psychology, Calcutta University, 92, Upper Circular Road, Calcutta.
23. BOSE, N. K., M.Sc., Ph.D., Offg. Director, Punjab Irrigation Research Institute, Lahore. (1938).
24. BOSE, S. N., M.Sc., Professor of Physics, Dacca University, Dacca.
25. BOSE, S. R., M.A., Ph.D., F.R.S.E., Professor of Botany, Carmichael Medical College, Calcutta. (1935).
26. BRAHMACHARI, SIR U. N., Kt., Rai Bahadur, M.A., M.D., Ph.D., F.R.A.S.B., K.I.H., Physician, Medical College Hospitals, Calcutta (Retired), 82-3, Cornwallis Street, Calcutta.

27. BURNS, W., C.I.E., D.Sc., I.A.S., Agricultural Expert, Imperial Council of Agricultural Research, New Delhi. (1935).

28. BURRIDGE, W., D.M., M.A. (Oxon), Professor of Physiology, Lucknow University, Lucknow.

29. BURT, SIR B. C., Kt., C.I.E., M.B.E., B.Sc., I.A.S., Vice-Chairman, Imperial Council of Agricultural Research, New Delhi.

30. CALDER, C. C., B.Sc. (Agr.), F.L.S., 18 Gladstone Place, Aberdeen, Scotland.

31. CHAKRAVARTI, S. N., M.Sc., D.Phil., F.C.S., Chemical Examiner to the Government of U.P. and C.P., Agra. (1935).

32. CHAMPION, H.G., M.A., Conservator of Forests, Western Circle, Naini Tal, United Provinces.

33. CHATTERJEE, G., M.Sc., Meteorologist-in-charge, Upper Air Observatory, Agra. (1935).

34. CHAUDHURI, H., M.Sc., D.Sc., Ph.D., D.I.C., Reader and Head of University Teaching in Botany and Director, Kashyap Research Laboratory, Punjab University, Lahore.

35. CHOPRA, B. N., D.Sc., F.L.S., Assistant Superintendent, Zoological Survey of India, Indian Museum, Calcutta. (1935).

36. CHOPRA, BREVET-COL. R. N., C.I.E., M.D., Sc.D., F.R.A.S.B., K.H.P., I.M.S., Director, School of Tropical Medicine, Calcutta.

37. CHOWDHURY, J. K., M.Sc., Dr.Phil. (Berlin), Reader in Chemistry, Dacca University, Ramna, Dacca. (1938).

38. CHOWLA, S., M.A., Ph.D., Professor of Mathematics, Government College, Lahore.

39. COUGHMAN, BRIGADIER SIR HAROLD, Kt., D.S.O., M.C., c/o Lloyds Bank Ltd., R. Dept., 6, Pall Mall, London, S.W. 1.

40. COULSON, A. L., D.Sc., D.I.C., F.G.S., Superintending Geologist, Geological Survey of India, Indian Museum, Calcutta. (1935).

41. CROOKSHANK, H., B.A., D.Sc., B.A.I., Superintending Geologist, Geological Survey of India, Indian Museum, Calcutta. (1938).

42. DASTUR, R. H., M.Sc., Cotton Physiologist, Agricultural College, Lyallpur, Punjab.

43. DATTA, S., M.Sc., D.Sc., D.I.C., Professor of Physics, Presidency College, Calcutta. (1935).

44. DATTA, CAPTAIN S. C. A., B.Sc., M.R.C.V.S., Veterinary Research Officer, Imperial Veterinary Research Institute, Muktesar-Kumaun, U.P. (1938).

45. DEY, B. B., D.Sc., F.I.C., I.E.S., Professor of Chemistry, Presidency College, Madras.

46. DHAR, N. R., D.Sc., F.I.C., I.E.S., Deputy Director of Public Instruction, U.P., Allahabad.

47. DHAR, S. C., M.Sc., D.Sc. (Cal., Edin.), F.R.S.E., Professor and Head of the Department of Mathematics, Nagpur University, Nagpur. (1938).

48. DUNN, J. A., D.Sc., D.I.C., F.G.S., Geologist, Geological Survey of India, Indian Museum, Calcutta. (1935).

49. DUNNICLIFF, H. B., M.A., Sc.D., F.I.C., I.E.S., University Professor of Inorganic Chemistry, Government College, Lahore.

50. DUTT, S. B., D.Sc., D.I.C., Reader in Organic Chemistry, Allahabad University, Allahabad. (1935).

51. EVANS, P., B.A., F.G.S., Geologist, The Burmah Oil Company, Ltd., P.O. Digboi, Assam.

52. FERMOR, SIR LEWIS L., Kt., O.B.E., D.Sc., A.R.S.M., M.Inst.M.M., F.G.S., F.R.A.S.B., F.R.S., c/o Lloyds Bank, 6, Pall Mall, London, S.W. 1.

53. FOWLER, GILBERT J., D.Sc., F.I.C., Consulting Chemist, Mackay's Gardens Annexe, Grames Road, Cathedral P.O., Madras.

54. FOX, C. S., D.Sc., M.I.Min.E., Superintending Geologist, Geological Survey of India, Indian Museum, Calcutta.

55. GEE, E. R., M.A., F.G.S., Geologist, Geological Survey of India, Indian Museum, Calcutta. (1935).

56. GHOSE, S. L., M.Sc., Ph.D., Professor of Botany, Government College, Lahore.

57. Ghosh, J., M.A., Ph.D., Professor of Mathematics, Presidency College, Calcutta. (1936).
58. Ghosh, J. C., D.Sc., Professor and Head of the Department of Chemistry, Dacca University, Ramna, Dacca.
59. Ghosh, P. N., M.A., Ph.D., Sc.D. (Hon.), F.Inst.P., Ghose Professor of Applied Physics, Calcutta University, 92, Upper Circular Road, Calcutta.
60. Glennie, Lt.-Col. E. A., D.S.O., R.E., Survey of India, Dehra Dun.
61. Gravely, F. H., D.Sc., F.R.A.S.B., Superintendent, Government Museum, Museum House, Egmore, Madras.
62. Guha, B. S., M.A., Ph.D., Assistant Superintendent, Zoological Survey of India, Indian Museum, Calcutta.
63. Guha, P. C., D.Sc., Acting Professor of Organic Chemistry, Indian Institute of Science, Hebbal, Bangalore. (1935).
64. Haddow, J. R., B.Sc., M.R.C.V.S., D.V.S.M., Offg. Director, Imperial Veterinary Research Institute, Muktesar-Kumaun, U.P.
65. Hendry, D., M.C., B.Sc., N.D.A., Director, Imperial Chemical Industries, India, Calcutta.
66. Heron, A. M., D.Sc., F.G.S., F.R.G.S., F.R.S.E., F.R.A.S.B., Director, Geological Survey of India, Indian Museum, Calcutta.
67. Hora, S. L., Rai Bahadur, D.Sc., F.R.S.E., F.L.S., F.Z.S., F.R.A.S.B., Asst. Superintendent, Zoological Survey of India, Indian Museum, Calcutta.
68. Husain, M. Afzal, Khan Bahadur, M.A., M.Sc., I.A.S., Vice-Chancellor, Punjab University, Lahore.
69. Iyengar, M. O. P., M.A., Ph.D., F.L.S., University Professor of Botany, Madras University, Triplicane, Madras.
70. Joshi, A. C., D.Sc., Assistant Professor of Botany, Benares Hindu University, Benares. (1938).
71. Kapur, S. N., Ph.D., Imperial Forest Research Institute, Dehra Dun.
72. Kichlu, P. K., D.Sc., Professor of Physics, Government College, Lahore. (1935).
73. Koshy, P. K., F.R.C.P., Professor of Anatomy, Medical College, Madras.
74. Kothari, D. S., M.Sc., Ph.D., Reader and Head of the Physics Department, Delhi University, Delhi. (1936).
75. Krishna, S., Ph.D., D.Sc., F.I.C., Forest Biochemist, Imperial Forest Research Institute, Dehra Dun (U.P.).
76. Krishnan, K. S., D.Sc., Mahendra Lal Sircar Professor of Physics, Indian Association for the Cultivation of Science, 210, Bow Bazar Street, Calcutta.
77. Krishnan, K. V., M.B.B.S., L.R.C.P., D.B., D.Sc., Professor of Malariology and Rural Hygiene, All-India Institute of Hygiene & Public Health, Calcutta.
78. Krishnan, M. S., A.R.C.S., Ph.D., D.I.C., Geologist, Geological Survey of India, Indian Museum, Calcutta. (1935).
79. Lal, R. B., M.B.B.S., D.P.H., D.T.M. & H., D.B., Offg. Director, All-India Institute of Hygiene & Public Health, Calcutta. (1935).
80. Law, S. C., M.A., B.L., Ph.D., M.B.O.U., 50, Kailas Bose Street, Calcutta. (1936).
81. MacMahon, P. S., M.Sc., B.Sc. (Oxon), F.I.C., I.E.S., University Chemical Laboratory, Pembroke Street, Cambridge.
82. Mahajani, G. S., M.A., Ph.D., M.L.C., Principal and Professor of Mathematics, Fergusson College, Poona 4.
83. Mahalanobis, P. C., M.A., B.Sc., I.E.S., Professor of Physics, Presidency College, Calcutta.
84. Maheswari, P., D.Sc., Lecturer in Botany, Allahabad University, Allahabad. (1935).
85. Matthai, George, M.A., Sc.D., F.L.S., F.Z.S., F.R.S.E., Professor of Zoology, Government College, Lahore.
86. Mehra, H. R., M.Sc., Ph.D., Reader in Zoology, Allahabad University, Allahabad.
87. Mehta, K. C., Rai Bahadur, M.Sc., Ph.D., Professor of Botany, Agra College, Agra.
88. Mills, J. P., M.A., I.C.S., Secretary to H.E. the Governor of Assam, Stonylands, Shillong, Assam. (1936).
89. Mitra, S. K., M.B.E., D.Sc., Ghose Professor of Physics, Calcutta University, 92, Upper Circular Road, Calcutta.

90. MITTER, P. C., M.A., Ph.D., Palit Professor of Chemistry, Calcutta University, 92, Upper Circular Road, Calcutta.

91. MOHAMMAD, WALI, M.A., Ph.D., I.E.S., University Professor of Physics, Lucknow University, Lucknow.

92. *MOWDAWALLA, F. N., M.A., M.I.E.E., Mem.A.I.E.E., M.I.E., 301, Frere Road, Fort, Bombay.*

93. *MUKHERJEE, J. N., D.Sc., F.C.S., F.R.A.S.B., Ghose Professor of Chemistry, Calcutta* University, 92, Upper Circular Road, Calcutta.

94. NAIK, K. G., D.Sc., F.I.C., Professor of Chemistry, Baroda College, Baroda.

95. NARAYAN, A.L., M.A., D.Sc., F.I.P., Director, Solar Physics Observatory, Kodaikanal.

96. NEOGI, P., M.A., Ph.D., I.E.S., 21, Kundu Lane, Belgachia, Calcutta. (1936).

97. NORMAND, C. W. B., M.A., D.Sc., Director-General of Observatories, Meteorological Office, Poona 5.

98. OLVER, COL. SIR ARTHUR, C.B., C.M.G., F.R.C.V.S., Principal, Royal Veterinary College, Edinburgh.

99. PARANJPE, G. R., M.Sc., A.I.I.Sc., I.E.S., Principal and Professor of Physics, Royal Institute of Science, Bombay. (1937).

100. PARANJPYE, R. P., D.Sc., Fergusson College Road, Poona 4.

101. PARIJA, P. K., M.A., B.Sc., I.E.S., Principal and Professor of Botany, Ravenshaw College, Cuttack.

102. PARKINSON, C. E., Deputy Conservator of Forests, Minbu Division, Minbu, Burma. (1936).

103. PERCIVAL, F. G., Ph.D., F.G.S., Superintendent of Mines and Quarries, Tata Iron & Steel Co., Ltd., 3 Beldih Lake Road, Jamshedpur. (1936).

104. PHILPOT, H. P., B.Sc. (Eng.), A.M.Inst.C.E., M.I.Mech.E., M.I.A.E., M.I.M., Principal and Jodhpur Hardinge Professor of Technology, Engineering College, Benares Hindu University, Benares.

105. PINFOLD, E. S., M.A., F.G.S., Geologist, The Attock Oil Co., Ltd., Rawalpindi.

106. PRASAD, B. N., M.Sc., D.Sc., Ph.D., Mathematics Department, Allahabad University, Allahabad. (1936).

107. PRASAD, MATA, D.Sc., F.I.C., Professor of Inorganic and Physical Chemistry, Royal Institute of Science, Bombay. (1935).

108. PRASHAD, BAINI, D.Sc., F.R.S.E., F.L.S., F.Z.S., F.R.A.S.B., Director, Zoological Survey of India, Indian Museum, Calcutta.

109. PRUTHI, H. S., M.Sc., Ph.D., Imperial Entomologist, Imperial Institute of Agricultural Research, New Delhi.

110. QURESHI, MUZAFARUDDIN, Ph.D., Professor of Chemistry, Osmania University, Hyderabad (Deccan).

111. RAJ, B. SUNDARA, Dewan Bahadur, M.A., Ph.D., Director of Fisheries, Madras. (1935).

112. RAMANATHAN, K. R., M.A., D.Sc., Meteorologist, Colaba Observatory, Bombay.

113. RAMDAS, L. A., M.A., Ph.D., Agricultural Meteorologist, Poona 5. (1935).

114. RANGASWAMI AYYANGAR, G. N., Rao Bahadur, B.A., I.A.S., Millets Specialist, Agricultural Research Institute, P.O. Lawley Road, Coimbatore, S.I.

115. RAO, B. RAMA, M.A., D.I.C., F.G.S., Director, Geological Survey Department, Mysore State, Bangalore.

116. RAO, C. V. HANUMANTHA, M.A., Professor of Mathematics, Punjab University, Lahore.

117. RAO, H. SRINIVASA, M.A., D.Sc., Assistant Superintendent, Zoological Survey of India, Indian Museum, Calcutta. (1937).

118. RAO, K. RANGADHAMA, D.Sc. (Madras and London), Reader in Physics, Andhra University, Waltair. (1937).

119. RAY, B. B., D.Sc., Khaira Professor of Physics, Calcutta University, 92, Upper Circular Road, Calcutta. (1935).

120. RAY, J. N., D.Sc., Ph.D., F.I.C., Professor of Organic Chemistry, University Chemical Laboratories, Punjab University, Lahore. (1935).

121. Ray, Sir P. C., Kt., M.A., Ph.D., D.Sc., F.R.A.S.B., Emeritus Professor of Chemistry, Calcutta University, 92, Upper Circular Road, Calcutta.

122. Ray, P. R., M.A., Khaira Professor of Chemistry, Calcutta University, 92, Upper Circular Road, Calcutta.

123. Row, Lt.-Col. R., M.D., D.Sc., I.M.S. (Hon.), 27 New Marine Lines, Bombay 1.

124. Roy, S. C., Rai Bahadur, M.A., B.L., Editor, 'Man in India', Ranchi.

125. Saha, M. N., D.Sc., F.R.S., F.R.A.S.B., Palit Professor of Physics, Calcutta University, 92, Upper Circular Road, Calcutta.

126. Sahni, B., M.A., Sc.D., D.Sc., F.R.S., University Professor of Botany, Lucknow University, Lucknow.

127. Sarkar, P. B., Dr. ès Sc., A.I.C., Lecturer in Chemistry, Calcutta University, 92, Upper Circular Road, Calcutta. (1935).

128. Sen, B. M., M.A., M.Sc., I.E.S., Principal, Presidency College, Calcutta.

129. Sen, H. K., M.A., D.Sc., D.I.C., Director, Indian Lac Research Institute, Namkum, Ranchi.

130. Sen, J. M., B.Sc., M.Ed. (Leeds), Dip. Ed. (Oxford), T.D. (London), F.R.G.S., Principal, Krishnagar College, Krishnagar. (1935).

131. Sen, N. R., D.Sc., Ph.D., Ghose Professor of Applied Mathematics, Calcutta University, 92, Upper Circular Road, Calcutta.

132. Sengupta, N. N., Ph.D., Professor of Psychology, Lucknow University, Lucknow.

133. Seymour Sewell, Lt.-Col. R. B., C.I.E., M.A., Sc.D., F.R.S., M.R.C.S., L.R.C.P., F.Z.S., F.L.S., Zoological Laboratory, Cambridge. (1936).

134. Shortt, Lt.-Col. H. E., I.M.S., London School of Hygiene and Tropical Medicine, Keppel Street, London, W.C. 1.

135. Siddiqi, M. R., M.A., Ph.D., Professor of Mathematics, Osmania University, Hyderabad. (1937).

136. Singh, B. K., M.A., Sc.D., F.I.C., I.E.S., Professor of Chemistry, Science College, Bankipore, Patna.

137. Sinton, Lt.-Col. J. A., V.C., O.B.E., M.D., D.Sc., D.P.H., D.T.M., I.M.S., Malaria Laboratory, Horton Hospital, Epsom, Surrey, England.

138. Sircar, A. C., M.A., Ph.D., Professor of Chemistry, Presidency College, Calcutta. (1937).

139. Sokhey, Lt.-Col. S. S., M.A., M.D., D.T.M. & H., I.M.S., Director, Haffkine Institute, Parel, Bombay.

140. Soparkar, M. B., M.D., B.Hy., Research Officer, Cholera Inquiry, Indian Research Fund Association, King Institute of Preventive Medicine, Guindy, Madras. (1937).

141. Spencer, E., D.Sc., Ph.D., F.I.C., A.R.S.M., M.I.M.M., F.G.S., Consulting Chemist, Bird & Co., Chartered Bank Buildings, Clive Street, Calcutta.

142. Srivastava, P. L., M.A., D.Phil., Reader in Mathematics, Allahabad University, Allahabad. (1935).

143. Subrahmanyan, V., D.Sc., F.I.C., Professor of Biochemistry, Indian Institute of Science, Bangalore.

144. Sulaiman, The Hon'ble Sir S. M., Kt., M.A., LL.D., D.Sc., Judge of the Federal Court of India, New Delhi. (1937).

145. Sur, N. K., D.Sc., Meteorologist, India Meteorological Department, Poona 5. (1938).

146. Taylor, Col. J., C.I.E., D.S.O., M.D., D.P.H., V.H.S., I.M.S., Director, Central Research Institute, Kasauli (Simla Hills).

147. Temple, F. C., (Hony. Col.) A.F. (I.), C.I.E., V.D., A.D.C., 28, Victoria Street, London, S.W. 1, England. (1937).

148. Tirumurti, T. S., Rao Bahadur, B.A., M.B. & C.M., D.T.M. & H., Principal, Stanley Medical College, Madras.

149. Ukil, A. C., M.B., M.S.P.E., Tuberculosis Research Officer, All-India Institute of Hygiene and Public Health, Calcutta. (1935).

150. Venkataraman, T. S., Rao Bahadur, B.A., I.A.S., Imperial Sugar Cane Specialist, P.O. Lawley Road, Coimbatore.

151. VENKATESACHAR, B., Rao Bahadur, M.A., F.Inst.P., Offg. Director, Indian Institute of Science, Hebbal, Bangalore.

152. *VIJAYARAGHAVAN, T., Ph.D. (Oxon), Reader in Mathematics, Dacca University, Ramna, Dacca.*

153. *VISWANATH, B., Rao Bahadur, F.I.C., Director, Imperial Agricultural Research Institute, New Delhi.*

154. *WADIA, D. N., M.A., B.Sc., F.G.S., F.R.G.S., F.R.A.S.B., Mineralogist to the Ceylon Government, c/o G.P.O., Colombo.*

155. WARE, F., C.I.E., F.R.C.V.S., I.V.S., Animal Husbandry Expert, Imperial Council of Agricultural Research, New Delhi.

156. WEST, W. D., M.A. (Cantab.), Geologist, Geological Survey of India, Indian Museum, Calcutta.

157. WHEELER, T. S., D.Sc., Ph.D., F.R.C.Sc.I., F.I.C., F.Inst.P., M.I.Chem.E., State Chemist, State Laboratory, Upper Merrion St., Dublin, Eire.

HONORARY FELLOWS.

1. PROF. NIELS BOHR, N.L., 15, Blegdamsvej, Copenhagen.
2. PROF. F. O. BOWER, Sc.D. (Cantab.), LL.D., F.R.S., Emeritus Professor of Botany, Glasgow University, 2, The Crescent, Ripon, Yorks.
3. PROF. LUDWIG DIELS, Director-General of the Botanical Garden and Museum, 7, Königin Luise Strasse, Berlin-Dahlem, Germany.
4. PROF. F. G. DONNAN, F.R.S., Formerly Director, Sir William Ramsay Laboratory, University College, 23 Woburn Square, London, W.C. 1.
5. SIR ARTHUR EDDINGTON, D.Sc., LL.D., F.R.S., Plumian Professor of Astronomy and Experimental Philosophy, Cambridge University, Cambridge.
6. PROF. ALBERT EINSTEIN, N.L., Princeton University, New Jersey, U.S.A.
7. SIR JAMES G. FRAZER, O.M., D.C.L., LL.D., Litt.D., Trinity College, Cambridge.
8. SIR THOMAS H. HOLLAND, K.C.S.I., K.C.I.E., D.Sc., F.R.S., Principal of the University of Edinburgh.
9. SIR FREDERICK GOWLAND HOPKINS, Kt., M.A., D.Sc., N.L., F.R.S., Sir William Dunn Professor of Biochemistry in the University of Cambridge.
10. SIR ARTHUR B. KEITH, M.D., F.R.C.S., LL.D., F.R.S., Buckston Browne Farm, Downe, Farnborough, Kent, England.
11. SIR GUY A. K. MARSHALL, C.M.G., F.R.S., Director, Imperial Institute of Entomology, London.
12. PROF. J. PERRIN, N.L., Sorbonne, Paris.
13. PROF. ROBERT ROBINSON, D.Sc., F.R.S., Waynflete Professor of Organic Chemistry in the Dyson Perrins Laboratory, Oxford University.
14. SIR E. JOHN RUSSELL, D.Sc., F.R.S., Director, Rothamsted Agricultural Experimental Station, Harpenden, Herts, England.
15. SIR ALBERT C. SEWARD, D.Sc., Hon. LL.D., F.R.S., Formerly Master of Downing College and Emeritus Professor of Botany in the University of Cambridge, 209, Cromwell Road, London, S.W. 5.
16. SIR CHARLES S. SHERRINGTON, O.M., G.B.E., N.L., F.R.S., Formerly Waynflete Professor of Physiology in the University of Oxford, Broomside, Valley Road, Ipswich, England.
17. DR. C. M. WENYON, C.M.G., C.B.E., F.R.S., Director-in-chief, Wellcome Bureau of Scientific Research, 183, Euston Road, London, N.W. 1.

APPENDIX II.

ABSTRACT PROCEEDINGS OF THE COUNCIL, 1938.

[NOTE.—These abstracts of the proceedings of the Council relate to questions dealt with which are likely to be of interest to Fellows. Routine matters and matters which are under consideration are not included.]

1. The Council resolved in connection with the Institute's publications that no alterations in the illustrations of papers could be made after acceptance, except at the cost of the author, and that author's corrections should not exceed more than 20% of the cost of setting up the paper. (Nos. 3-4—26-2-38.)

APPENDIX III.

COMMITTEES, 1939.

SECTIONAL COMMITTEES.

	To serve until Dec. 31.
(1) 'Mathematics' Committee for Mathematics, Astronomy and Geodesy:—	
Prof. K. Ananda Rao	1939.
Lt.-Col. E. A. Glennie	1939.
Principal G. S. Mahajani	1940.
Principal B. M. Sen (Secretary and Convener)	1940.
Prof. A. C. Banerji	1941.
Prof. M. R. Siddiqi	1941.
(2) 'Physics' Committee for Physics and Meteorology:—	
Prof. B. Venkatesachar	1939.
Prof. D. M. Bose (Secretary and Convener)	1939.
Dr. D. S. Kothari	1940.
Prof. S. K. Mitra	1940.
Dr. K. R. Ramanathan	1941.
Prof. M. N. Saha	1941.
(3) 'Chemistry' Committee for Pure and Applied Chemistry:—	
Prof. V. Subrahmanyan	1939.
Prof. J. N. Mukherjee (Secretary and Convener)	1939.
Prof. B. B. Dey	1940.
Prof. J. C. Ghosh	1940.
Dr. H. K. Sen	1941.
Rao Bahadur B. Viswanath	1941.
(4) 'Engineering Sciences' Committee for Engineering, Metallurgy, Electro-technics and kindred subjects:—	
Principal H. P. Philpot	1939.
Mr. E. S. Pinfold	1939.
Dr. G. J. Fowler	1940.
Dr. E. Spencer	1940.
Dr. N. K. Bose	1941.
Mr. D. Hendry (Secretary and Convener)	1941.

(5) 'Geology' Committee for Geology, Palæontology, Mineralogy and Geography:—

Mr. D. N. Wadia	1939.
Mr. W. D. West	1939.
Dr. M. S. Krishnan	1940.
Dr. F. G. Percival	1940.
Dr. A. L. Coulson (Secretary and Convenor)	1941.
Dr. C. S. Fox	1941.

(6) 'Botany' Committee for Pure and Applied Botany, Forestry and Agronomy:—

Mr. H. G. Champion	1939.
Prof. K. C. Mehta	1939.
Dr. S. L. Ghose	1940.
Prof. S. P. Agharkar (Secretary and Convener)	1940.
Prof. B. Sahni	1941.
Rao Bahadur T. S. Venkataraman	1941.

(7) 'Zoology' Committee for Pure and Applied Zoology and Anthropology including Ethnology:—

Dr. B. S. Guha (Secretary and Convener)	1939.
Dr. H. S. Pruthi	1939.
Prof. G. Matthai	1940.
Dr. B. Sundara Raj	1940.
Dr. C. F. C. Beeson	1941.
Rai Bahadur S. C. Roy	1941.

(8) 'Physiology' Committee for Animal Physiology, Pathology, Bacteriology, Psychology and other Medical and Veterinary subjects:—

Prof. W. Burridge	1939.
Dr. R. B. Lal (Secretary and Convener)	1939.
Prof. N. N. Sengupta	1939.
Dr. A. C. Ukil	1940.
Lt.-Col. H. E. Shortt	1940.
Lt.-Col. S. S. Sokhey	1940.
Col. R. Row	1941.
Dr. G. Bose	1941.
Mr. J. R. Haddow	1941.

APPENDIX IV.

LIST OF INSTITUTIONS ON THE EXCHANGE LIST.

Indian.

Allahabad.

1. Allahabad University.
2. National Academy of Sciences, India.

Bangalore.

3. Department of Agriculture, Mysore State.
4. Electrical Engineering Society.
5. Geological Survey Department, Mysore State.
6. Meteorological Department, Mysore State.
7. Indian Academy of Sciences.
8. Indian Institute of Science.
9. Society of Biological Chemists, India.

Bombay.

10. Anthropological Society of Bombay.
11. Bombay Natural History Society.
12. Indian Central Cotton Committee.
13. Royal Institute of Science.

Calcutta.

14. Royal Agri-Horticultural Society of India.
15. Anthropological Society of India.
16. Biochemical Society of India.
17. Botanical Survey of India.
18. Calcutta Mathematical Society.
19. Calcutta Medical Club.
20. Calcutta University.
21. Carmichael Medical College.
22. Geological, Mining and Metallurgical Society of India.
23. Geological Survey of India.
24. Indian Association for the Cultivation of Science.
25. Indian Chemical Society.
26. Indian Medical Gazette—(Thacker, Spink & Co. (1933), Ltd).
27. Indian Physical Society.
28. Indian Psychological Association.
29. Indian Statistical Institute.
30. Indian Tea Association.
31. Institution of Chemists, India.
32. Mining, Geological and Metallurgical Institute of India.
33. Physiological Society of India.
34. Royal Asiatic Society of Bengal.
35. Science and Culture.
36. Survey of India.
37. Zoological Survey of India.

Coonoor.

38. Pasteur Institute of Southern India.

Dacca.

39. Dacca University.

Dehra Dun.

40. Board of Management, Indian Forester.
41. Imperial Forest Research Institute.

Hyderabad (Deccan).

42. Department of Mines and Geological Survey, H.E.H. the Nizam's Government.
43. Osmania University.

Indore.

44. Institute of Plant Industry.

Kasauli.

45. Central Research Institute.
46. Indian Journal of Medical Research.
47. Malaria Institute of India.

Lahore.

48. Punjab University.

Lucknow.

49. Indian Zoological Memoirs.

Madras.

50. Indian Botanical Society.
51. King Institute of Preventive Medicine.
52. Madras Fisheries Department.
53. Madras Government Museum.

Muktesar.

54. Imperial Veterinary Research Institute.

Naggar (Punjab).

55. Himalayan Research Institute, Roerich Museum.

New Delhi.

56. Imperial Council of Agricultural Research.

Poona.

57. India Meteorological Department.
58. Indian Mathematical Society.

Ranchi.

59. Indian Lac Research Institute.

Simla.

60. Himalayan Club.

Foreign.

Canada.

61. Department of Mines, Ottawa.
62. Geological Survey of Canada, Ottawa.

Cape Colony.

63. South African Library, Cape Town.

China.

64. National Agricultural Research Bureau, Nanking.

France.

65. Museum Natural d'Histoire Naturelle, Paris.

Germany.

66. Chemisches Zentralblatt, Berlin.

Great Britain.

67. British Museum, Natural History Section, London.
68. Imperial Bureau of Plant Genetics (for crops other than Herbage), Cambridge
69. Imperial Bureau of Plant Genetics (Herbage plants), Aberystwyth.
70. Nature, London.
71. Patent Office, London.
72. Royal Botanic Gardens, Edinburgh.
73. Royal Society of Edinburgh.
74. Science Museum, London.

Italy.

75. Institut International d'Agriculture, Rome.

Java.

76. Departement van Economische Zaken, Batavia.

Philippines.

77. Philippine Bureau of Science, Manila.

Russia.

78. All-Union Lenin Library, Moscow.

Uganda.

79. Geological Survey of Uganda.

U.S.A.

80. American Chemical Society, Columbus, Ohio.
81. American Museum of Natural History, New York.
82. Marine Biological Laboratory, Woods Hole, Mass.
83. Scripta Mathematica, New York.
84. Treasury Department, U.S. Public Health Service, Washington.
85. U.S. Department of Agriculture, Washington.

APPENDIX V.

LIST OF PERIODICALS RECEIVED IN EXCHANGE OR AS PRESENTATION.

Indian.

Agriculture and Livestock in India.
Annual Report of the Indian Central Cotton Committee.
Annual Report of the Imperial Veterinary Research Institute, Muktesar.
Annual Report of the Indian Association for the Cultivation of Science.
Annual Review of Biochemical and Allied Research in India.
Bulletin of the Indian Central Cotton Committee.
Bulletin of the Calcutta Mathematical Society.
Bulletin of the Department of Industries, Bombay.
Bulletin of the Geological, Mining and Metallurgical Society of India.
Bulletin of the Madras Government Museum.
Bulletin of the Mysore Coffee Experiment Station.
Calcutta Medical Journal.
General Report of the Survey of India.
Indian Forest Records.
Indian Forester.
Indian Journal of Agricultural Science.
Indian Journal of Physics.
Indian Journal of Medical Research.
Indian Journal of Veterinary Science and Animal Husbandry.
Indian Medical Gazette.
Indian Medical Research Memoirs.
Indian Zoological Memoirs.
Journal of the Department of Science, Calcutta University.
Journal of the Indian Chemical Society.
Journal of the Indian Institute of Science, Bangalore.
Journal of the Indian Mathematical Society.
Journal of the Indian Medical Association.
Journal of the Malaria Institute, India.
Journal of the University of Bombay.
Jubilee Volume of the Anthropological Society, Bombay.
Madras Fisheries Bulletin.
Memoirs of the Geological Survey of India.
Mysore Agricultural Calendar.
Nagpur University Journal.
Proceedings of the 25th Indian Science Congress.
Proceedings of the Indian Academy of Sciences, Bangalore.
Proceedings of the National Academy of Sciences, India.
Proceedings of the Society of Biological Chemists.
Punjab Forest Records.
Quarterly Bulletin of the Central Board of Irrigation.
Quarterly Journal of the Geological, Mining and Metallurgical Society of India.
Records of the Botanical Survey of India.
Records of the Geological Society of India.
Records of the Malaria Institute of India.

Records of the Mysore Geological Department.
Report of the Botanical Survey of India.
Report of the Irwin Canal Soil Survey.
Report of the King Institute of Preventive Medicine, Madras.
Report of the Madras Fisheries Department.
Science and Culture.
Scientific Monographs of the Imperial Council of Agricultural Research.
Scientific Notes of the Indian Meteorological Department.
Statistical Leaflets of the Indian Central Cotton Committee.
Summary Proceedings of the Meetings of the Indian Central Cotton Committee.
Supply and Distribution of the various types of Indian Cotton during the session 1936-37.
The Mathematics Student.
Transactions of the Mining, Geological and Metallurgical Institute of India.

Foreign.

American Museum Novitates, New York.
Annals Jardin Botanique, Buitenzorg.
Annual Report of the British Museum.
Annual Report of the Geological Survey Department of Uganda.
Biological Bulletin of the Marine Biological Laboratory, Woods Hole, Mass., U.S.A.
Berichte der Deutschen Chemischen Gesellschaft, Berlin.
Bulletin of the Canada Department of Mines.
Bulletin Jardin Botanique, Buitenzorg.
Bulletin (Herbage Publication Series), Imperial Bureau of Plant Genetics, Aberystwyth.
Bulletin Museum d'Histoire Naturelle, Paris.
Bulletin of the U.S. National Museum, Washington.
Chronica Botanica, Leyden.
Collected Reprints of the Woods Hole Oceanographic Institute.
Contributions from the U.S. Herbarium, Washington.
Crop Reports of the National Agricultural Research Institute, Nanking.
Experiment Station Record, U.S. Department of Agriculture, Washington.
Himalayan Journal.
Journal of the American Chemical Society.
Journal Shanghai Institute of Science.
Memoirs of the Canada Department of Mines.
Memoirs of the Geological Survey of Uganda.
Notes from the Royal Botanic Gardens, Edinburgh.
Proceedings of the Royal Society of Edinburgh.
Proceedings of the U.S. National Museum.
Papers in Physical Oceanography and Meteorology, Woods Hole Oceanographic Institute.
Report of the Canadian Arctic Expedition, 1913–1918.
Report of the Canada Department of Mines.
Scripta Mathematica, New York.
Studies from the Department of Physics, Shanghai Institute of Science.
Technical News Bulletin of the National Bureau of Standards, Washington.
Transactions and Proceedings of the Botanical Society of Edinburgh.
Treubia.

APPENDIX VI.

THE NATIONAL INSTITUTE OF SCIENCES OF INDIA.

Receipts and Payments Account for the year ended 30th November, 1938.

RECEIPTS.	Rs. A. P.	Rs. A. P.
To Balance brought forward ..	....	35,817 4 3
,, Members' Admission Fees ..	....	512 0 0
,, Members' Subscriptions ..	....	4,984 0 0
,, Donations	....	50 14 0
,, Contributions towards publication of 'Indian Science Abstracts' ..	....	550 0 0
,, Sale of Authors' extra copies and publications ..	....	307 11 3
,, Interest on Investments ..	....	1,256 2 0
,, Grants-in-aid—		
Government of India ..	12,000 0 0	
Universities	500 0 0	
		12,500 0 0
,, Miscellaneous Receipts ..	..	4 6 0
TOTAL ..	....	55,982 5 6

PAYMENTS.		Rs. A. P.	Rs. A. P.
By Salaries of Staff		....	2,562 8 0
,, Printing Circulars, Notices, etc. ..		....	77 8 0
,, Printing Publications, Reports, etc.		....	3,605 15 6
,, Contributions to other Science Academies under Rule 19 ..		....	1,008 0 0
,, Honoraria, etc. for preparing abstracts for 'Indian Science Abstracts'		....	165 0 0
,, Postage		....	409 9 9
,, Stationery		....	93 7 0
,, Audit Fees		....	50 0 0
,, Travelling..		....	503 13 6
,, Rent of Office		....	200 0 0
,, Advances to Staff		....	9 0 0
,, Miscellaneous Expenses ..		....	82 15 6
,, Bank Charges		....	19 11 0
,, Cash and other Balances:—			
Investments—	Rs.		
3½% G.P. Notes 1842/43	5,000		
3½% ,, 1854/55	2,000		
3½% ,, 1865	6,000		
3½% ,, 1873	2,000		
3½% ,, 1900/01	8,000		
4% Loan 1960/70	10,000		
	33,000		
At cost		33,018 11 10	
With Imperial Bank of India—	Rs. A. P.		
On Savings Bank Account ..	2,145 2 0		
On Current Account ..	12,023 15 8		
		14,169 1 8	
In hand		6 15 9	
			47,194 13 3
TOTAL ..			55,982 5 6

Examined with the Books and Vouchers and found in accordance therewith.

PRICE, WATERHOUSE, PEAT & CO.
Chartered Accountants,
Registered Accountants. } *Auditors.*

CALCUTTA,
8th December, 1938.

APPENDIX VII.

BUDGET ESTIMATE FOR 1938-39.

	1937-38 Estimates.	1937-38 Actuals.	Budget Estimate for 1938-39.
Ordinary Receipts.			
	Rs.	Rs.	Rs.
Subscriptions	5,200	4,984	5,500
Interest	1,200	1,256	1,200
Contribution towards publication of 'Indian Science Abstracts' ..	500	550	500
Sale of publications	500	308	300
Grants-in-aid	....	500	700
Grant-in-aid from Government of India	12,000*	12,000*	6,000
Miscellaneous	....	4	....
Contribution from General Fund ..	....	....	2,450
	19,400	19,602	16,650
Extraordinary Receipts.			
Admission Fees	320	512	320
Donation	....	51	....
	320	563	320
Ordinary Payments.			
Salaries and allowances	2,700	2,562	2,700
Publications	9,000	3,683	9,000
Contribution to co-operating academies under Rule 19	1,000	1,008	1,200
Furniture	500	....	500
Postage	600	410	500
Stationery	150	93	150
Audit Fee	50	50	50
Honoraria, etc., for preparing abstracts for 'Indian Science Abstracts' ..	....	165	1,200
Travelling	....	504	600
Office Rent	....	200	600
Miscellaneous	600	112	150
Refunded to the General Fund ..	4,800	10,815	....
	19,400	19,602	16,650
Extraordinary Payments.			
Funding of Admission fees and Donation	320	563	320

* Grant for 2 years.

Annual Address to the National Institute of Sciences of India.

LAHORE, 1939.

By PROF. M. N. SAHA, *D.Sc.*, *F.R.S.*, *Palit Professor of Physics*, *Calcutta University*.

SOLAR CONTROL OF THE ATMOSPHERE.

CONTENTS.

I. GENERAL.

Last year we met at Calcutta under the congenial atmosphere of a great event in the annals of Indian Science—namely, the Silver Jubilee of the Indian Science Congress. Most of us will remember the thrill and joy of the occasion and the benefit we derived from a contact with our distinguished overseas guests. We held on that occasion a symposium on River Physics in which experts on different lines, geologists, zoologists, engineers actually concerned in field and laboratory operations, took part. The Report of the Symposium has been published so as to be available to the general public. This symposium had a wonderful reception in the Press, Indian as well as foreign, as it emphasized the need of organizing scientific study on a subject which is of the highest importance to the welfare of the Indian nation. Two other symposia were held in the course of the year, one at Poona on 'Weather Prediction' on the

25th and 26th of July and the second one at Bombay on the 26th and 27th of September on 'Recent work on the Synthesis of organic substances occurring in Nature'. Both these meetings, which dealt with matters of the highest practical importance, were very largely attended by actual workers on the subject. A number of public lectures were also given under the auspices of the National Institute of Sciences. It is my experience that these miniature Science Congresses, devoted to discussions on a particular subject provide far greater intellectual stimulus than the annual session, when one gets lost in the plethora of dinners, parties, and entertainments. I hope that the National Institute of Sciences will find it possible to organize a larger number of such symposia in future years.

Publications.

The publication of our Proceedings and Transactions has been continued. The Indian Science Abstracts for 1936 and 1937 have been almost completed and are in course of publication. Our General Editor, Dr. Baini Prashad, has with his characteristic energy made up our arrears, and hopes to bring them out within a short time. On account of the increasing nature of the work it has been found necessary to associate with him as Associate Editor, Dr. M. S. Krishnan, thus giving an accession of strength to our publication side.

Finances.

We have received from the Government of India grants for two years amounting to Rs.12,000. The universities of Calcutta, Osmania and Dacca, and the Imperial Council of Agricultural Research have agreed to continue their grants. Our grateful thanks are due to these bodies. We are this year issuing an appeal to the Provincial Governments and other States and we hope that some response will be found.

General Remarks.

We are glad to note that this year we have been lucky enough to suffer no losses by death. Our total number of Fellows (including the new entrants) has risen to 157. The fear expressed in certain quarters that on account of the constant addition of 10 per year our number would swell to unmanageable proportions is thus seen to be falsified. As a matter of fact for the last four years, there has been a steady balance between losses and gains. I feel, however, and this is strictly a personal opinion, that if the Institute is to be really useful to the Nation, the membership should be increased to at least 300, so that younger men of promise who have otherwise to wait for a long time, may be early admitted into the Institute—for, without accession of fresh blood, there can be no strength.

After two years of work, I am glad to lay down my office and hand over the charge to Brevet-Col. R. N. Chopra, one of the leading medical men and

pharmacologists of India. It is well known to you that as Director of the School of Tropical Medicine, Calcutta, Col. Chopra has built up a fine school of Research and as President of the Drug Enquiry Committee he has rendered unique services to the State. His original works and treatises on Indian Drugs have made him an International authority on the subject and I hope that under his distinguished guidance, the National Institute of Sciences will continue to make steady progress and achieve the ideal for which it was established. I wish also to thank my colleagues, the two Secretaries, Drs. Agharkar and Heron and our General Editor, Dr. Baini Prashad, for the loyal co-operation which I received from them. We worked like a team and I am glad to report to you that for the last two years there has not been a single occasion giving rise to any difference of opinion amongst us or fostering any ill-feeling due to controversial matters.

Before coming to the subject-matter of my address I wish to make some general remarks with respect to the future of Science in this country. It is probably well known to all of you that there have been three stages in the progress of Science in this country. First, due to the establishment of Scientific Surveys of the Government of India during the last century, a measure prompted by administrative needs, and second, in the early years of this century, due to the recognition of the different Sciences as subjects of study in the curricula of the universities and the starting of teaching universities in which research on scientific subjects was recognized to be one of the duties of the teachers, and research qualifications were regarded as a requisite to appointment and promotion to higher grades. I regret to note, however, that owing to intrigues by vested interests, and defects in the constitution, these ideals are being lost sight of, nay even abandoned in many of the universities, and some of them are being reconverted to the high school stage from which they were rescued by the reforms of 1921-22. I give a timely warning, so that the evil may be nipped in the bud, before it entirely destroys the foundations of learning and scholarship. The time has now come not only to strengthen the scientific surveys and the research atmosphere of the universities, but we ought to enter on a third phase, namely, scientific research should now be *applied* for solving the industrial problems of the country and properly trained scientific men should be more largely employed by the already existing industries.

As you are all aware, last year I devoted a large part of my address to the necessity of large scale industrialization of this country for solving the problems of poverty, unemployment and defence. It was supposed that the Indian public was averse to schemes of large scale industrialization as we find in foreign countries. But last year's discussions in the press have shown that this is not a correct representation of the public feeling. It is recognized that the problems of poverty and unemployment from which the Indian population suffers and which make her a bye-word of contempt amongst the civilized nations of the world can only be solved if the country plunges with feverish energy into schemes for exploiting the natural resources of the country and starting large

scale key industries. In my address last year I gave an indication of the extremely low level of prosperity in this country. Take whatever modern product you like, the number of units of electricity consumed, the number of radio sets or the number of motor cars used per head of population, the quantity of paper used, or the number of newspapers read, we have the same story, and it is found that India is about 200 times behind other countries. She is mainly a mass of mediæval humanity, without strength or cohesion, ready to be exploited by anybody. Present-day measures, both Government and private, to improve this state of affairs are extremely inadequate. For example, if the present policy of the All India Radio is not radically changed, we shall take 6,000 years to have the same number of radio sets in this country per head of population as in western countries. In fact this observation can be generalized. It can be shown with facts and figures that unless there is a fundamental and radical change in policy and in the activities of the people and the State, we shall have to wait for nearly 1,000 years to reach that level of prosperity which is enjoyed in modern times by Europe, America and Japan. It was, therefore, a great relief to find that the President of the Indian National Congress, Mr. Subhas Chandra Bose, declared it as a policy of the Indian National Congress that there must be a forced march as regards policies of industrialization in this country. We hope the National Planning Committee, which has been appointed, will produce a document which will give real guidance in this matter to the Indian people, and the National Planning Commission will devise ways and means to give effect to the recommendations of the Committee.

II. Solar Control of the Atmosphere.

Introduction.

Let me now come to the scientific part of my lecture. I wish to tell you about the Solar Control of the Atmosphere. It is a matter of common knowledge that weather and climate, so important to human life, are completely controlled by the Sun. But our troubles begin when we attempt to have precise knowledge of the way in which this control operates. This has been an eternal problem with mankind. In ancient communities, there was a profession of Weather Prophets whose duty it was to foretell and, if possible, to control with magic, the weather. Such was the importance attached to the office that a successful rain-maker was very often asked to rule over the tribe. But when he failed, as he must have done frequently, he was sacrificed before the altar of the tribal god. In later times, the office was transferred to Astrologers who are still found in many parts of the world issuing weather forecasts for the year. Scientific study of weather and climate dates from the time of the discovery of the barometer by Torricelli, but from the very nature of things, early meteorology could not find out a Newton, and it was realized that meteorological data must be patiently collected, classified and analyzed by a world-wide survey, before we can have any inkling of the secrets of the very

puzzling complex of phenomena presented by Meteorology. For this purpose, Meteorological Surveys have been organized almost by every State, and a system of short and long range forecasting has been undertaken. But short range forecasting owes, whatever success it can claim, more to powers of quick transmission of news rendered possible by modern discoveries in Physics than to any profound insight into the nature of the problems involved. But what would really benefit mankind is a system of successful long range forecasting six months or at least 10 to 15 days ahead. It is well known that the meteorologist has not succeeded in this task because the problems confronting him are too intricate and he has to deal with a large number of complex factors. I must not, however, forget to mention that within recent years, Franz Baur in Germany, and Multanovsky in Russia have developed methods for medium-range forecasting which have attained a certain amount of success. Their methods are based on combination of Synoptics and Statistics, and in Franz Baur's method, atmospheric conditions at a height of 5 kms. at any time are supposed to control ground weather for the next 10 days. But no physical basis has yet been found why this should be the case.

It would probably be considered strange that in spite of the great accretion in our knowledge of physics, and in spite of the large number of qualified men employed in the study of meteorology, we should be forced to admit that success still eludes us. Probably one of the reasons is, as one great Physicist once told the present writer, that meteorology has not yet engaged the attention of a Newton, or as I may add of a Bohr or Heisenberg. Another reason appears to me that the meteorologists long confined themselves to ground phenomena and neglected the Upper Regions. It is true, that in recent years, upper air surveys have been receiving greater and greater attention. There are the spectacular stratospheric flights, exploration of the Upper Atmosphere by Radio-meteorographs—instruments carried in balloons which signal by radio weather conditions up to heights of 30 kms.

It is usually thought that ground weather is controlled less by the interaction of solar radiation on the atmospheric gases of the sun, than by the direct heating of the surface of the earth by the solar rays. But in the light of the discovery of the stratospheric region towards the end of the last century, and plausible influence of upper air movements on ground weather possibly the upper air studies have been too much neglected. In view of the prospective use of the stratosphere for air-travel, and the use of the still higher region for radio propagation, probably the need will soon be felt for a better knowledge of not only the stratosphere, but also of the still higher regions. Here photochemical action of solar radiation on the atmospheric gases plays the chief part. For studying these reactions, we must have a good knowledge of the radiative properties of the sun, but it is not usually realized how defective and imperfect our knowledge in this respect is. We have not, as yet, a comprehensive knowledge of the reactions produced by sunlight on the constituents of our atmosphere.

The Ozone Screen.

The sun is regarded usually as a black body at 6000°K. But it has been known for a long time that this is only a first approximation. We find several very glaring deviations from the black body curve. Even after allowing for loss by absorption and scattering by the atmospheric constituents, we find that the emissivity of the sun cannot be referred to any definite temperature. Our knowledge is particularly defective in the ultra-violet region because the solar spectrum is abruptly cut off below λ 2900 Å. This was regarded as a great puzzle by the earlier workers. In 1881 Hartley showed that this abrupt termination of the solar spectrum is due to a small amount of ozone present in the atmosphere. Ozone is not distributed according to the laws of hydro-statics as in the case of the other gases, but was shown by Fabry and Buisson in 1913 to be localized in the upper regions. Interest has now shifted to an actual determination of the total amount of ozone in the atmosphere, its variation with altitude, season of the year and the time of the day. A successful carrying out of the programme involves a world-wide survey which has been initiated by Dobson, Götz and Meetham, and is being carried out in different countries of the world. But what is most surprising is the extremely small amount of ozone which is responsible for the complete obliteration of the whole solar spectrum between λ 2900 Å and λ 2200 Å. The amount is found to be not more than ·3 cm. of the gas at N.T.P. spread over the atmospheric layer from 20 km. to 50 km., and having a maximum density at about 30 km., but the amount undergoes variations which are clearly connected with meteorological conditions. The ozone itself is not an original constituent in the sense that O_2 or N_2 are, as in that case, instead of occurring at a height it would have settled down at the bottom, but this is not the case ; it has been found that O_3 is produced by the photochemical action of sunlight on the oxygen of the atmosphere in a way which is not yet completely elucidated. But this small amount is sufficient to cut off the whole amount of ultra-violet light below λ 3000 Å. In a sense this is lucky, as otherwise sunlight would have had a very harmful action on living matter on the earth and probably would have made life very trying, if not impossible.

Above the Ozone Screen.

Suppose we can push above the ozone screen. What would the spectrum of the sun be like? Such a feat does not appear to be quite impossible. In fact, Regener, to whom the world is indebted for the cosmic ray exploration of the Upper Atmosphere, sent up in his sounding balloon an automatically working spectrograph to a height of about 30 km. and secured the spectrum of the sun from this height. It was found that the ultra-violet limit is slightly pushed down and a much smaller time is needed to secure the solar spectrum at λ 2900 Å. It is quite possible, as was suggested by the present author in a Harvard Bulletin three years ago, that in the future automatically working

quartz or fluorite spectrographs would be regularly sent up in balloons up to a height of 50 km. and the spectrum of the sun below λ 3000 Å would be secured. Such work will greatly add to our knowledge of the radiation from the sun in this region, which is subject to greater fluctuations with disturbances on the sun than the spectral region directly accessible, and thus entirely set at rest speculation regarding solar radiation in this otherwise inaccessible region.

Aurora : Active Sun.

But as long as such direct evidences are not forthcoming, it will be necessary for us to obtain conclusions from indirect sources. These are the phenomena which are observed in the part of the atmosphere above the ozonosphere. This region does not contain more than 2 per cent of the total mass of the atmosphere, but it is found to be as much crowded with interesting phenomena, nay even more than the 98% down below. Amongst these phenomena, the best known is the Aurora or the polar lights which are familiar to the dwellers of the northern regions which suffer from a long winter night. The sky is frequently illuminated in these regions by brilliant flashes of light and these, naturally enough, have engaged the attention of generations of Scandinavian physicists, Birkeland in the early part of this century, Störmer, Vegard, Rosseland and their pupils at the present times. Even before systematic studies were started it was found that the occurrence of these northern lights was subject to solar control. It was found that the brilliancy and frequency of these auroral lights were not constant from year to year, but varied in the same way as the spots of the sun ; the period being nearly 10·32 years, roughly known as the 11 year period of the sun.

The close connection between sunspot activity and the occurrence of aurora led Birkeland to the view that auroral phenomena were probably due to injection of streams of electrons coming straight from the sun in a narrow jet into the atmosphere of the earth, a view which he further confirmed by laboratory experiments repeated in recent years by Brüche. The streams, on their entry into the earth's atmosphere, are deflected by the magnetic action of the earth's field and are focussed round about the magnetic pole. The complete mathematical theory of the orbits of electrons in the earth's atmosphere has been worked out by Störmer, in several important treatises. Paulsen, on the other hand, thought that the swarm of electrons, which produces the aurora, does not come direct from the sun, but is produced by ultra-violet rays of the sun acting photochemically on the constituents in the upper atmosphere. This theory has been worked out in great detail in recent years by Maris and Hulburt and supported by numerous cogent arguments. The great difficulty of Störmer's explanation is that according to his theory, the region of maximum occurrence of aurora would be a region about 2 to 3° round about the magnetic pole, while actually the zone of maximum occurrence forms a girdle of about 20° radius about the magnetic pole. Further, as Hulburt noted, the electron-projection theories are mostly geometrical and do not attempt to go into the

physics of the problem. For this, we must turn to an examination of the spectrum of the aurora which has been carried out for a long time by Vegard, Störmer and others. The most important line is a green line, the origin of which was unknown for a long time. As it apparently occurs at a great height of the atmosphere, at first sight it appeared that it must be due to a gas which is very light, even lighter than hydrogen. This hypothesis was rendered necessary because hydrodynamical calculations showed that with reasonable assumptions about the temperature distribution in the upper layers of the atmosphere, there would be very little of the heavier gases left at heights of about 200–300 kms. in the regions where the aurora appear. In fact, there would be scarcely a single molecule of nitrogen or oxygen in a cubic centimetre. The upper atmosphere would consist entirely of light elements like hydrogen and helium. But surprisingly enough, neither the green line nor any other auroral lines could be ascribed to either hydrogen or helium; hence we must exclude the possibility of the existence of these elements in the upper regions. This green line was therefore ascribed to a hypothetical element even lighter than hydrogen, called Geocoronium by Wegener. But when Moseley definitely proved that there was no place for such an element in the Periodic Table, it was found necessary to look for the origin of the lines from amongst the known elements. After an epic struggle, the line was traced, chiefly due to the efforts of the late Sir John MacLennan, to the old familiar oxygen atom, in a peculiar state of excitation. The reason why this identification was not made earlier is that the line does not occur in the ordinary discharge spectrum of oxygen. It is given by the oxygen atom when it is in a metastable condition, by what is known as the forbidden transition from one metastable level to another. Though the subtility of the origin of the line, and its implication, can only be realized by one having an intimate knowledge of spectroscopy, the discovery shows that oxygen, contrary to hydrodynamical conceptions, is present in the auroral regions (80 km.–400 km.) in the atomic state and in a peculiar state of excitation; a closer examination of which alone can lead us to a knowledge of the peculiar physical conditions prevailing in this region.

Further examination of the spectrum of the aurora reveals lines which have been identified with those of ionized nitrogen and neutral nitrogen molecules. Recently Kaplan has reported a forbidden line of atomic nitrogen. Before we turn to an examination of the solar control of the aurora, let us consider another associated phenomena.

Night Sky Phenomena : Quiet Sun.

But it is not merely the region round the magnetic poles which shows such unexpected behaviour. It has been well known that if one observes the sky from the countryside far away from the city lights at the dead of night, the starless parts of the sky do not appear to be absolutely dark, as one finds when one is placed in an absolutely light-tight chamber, but appear

to possess considerable luminosity. This must originate from the upper regions of the atmosphere, even at stations far removed from the magnetic poles; hence the luminosity must be due to some other cause besides artificial stimulation by electrons which give rise to aurora. An examination of the spectrum of the luminous night sky carried out at different regions of the world reveals very interesting information. It shows the same green line of oxygen and certain other band lines which have been identified with those of nitrogen. There is, however, one important difference between the spectrum of the night sky and of the aurora. In the latter, bands due to ionized nitrogen predominate and the lines due to uncharged nitrogen molecules are very feeble. The reverse is the case with the spectrum of the luminous night sky. Here the negative bands are faint and sometimes even absent, whereas band lines due to neutral nitrogen molecules are extremely strong. The origin of the luminescent night sky must be traced to the fact that at these heights sunlight is absorbed by the atmospheric gases in the daytime and stored in some way to be re-emitted at night. A closer examination of the phenomenon therefore promises to throw much light on the nature of the solar radiation, because the night sky phenomenon can be due to no other cause except the action of the ultra-violet rays of the sun below λ 2000 Å on the constituents of the upper atmosphere.

From the above short account, it will be clear that the luminescent night sky, and the aurora, both represent optical excitation of the constituents of the upper atmosphere, but under different conditions. The former is a purely photochemical excitation, by a normal sun—the latter is due to an active sun, and further complicated by the peculiar way in which optical excitation is provided through electrons which, according to one view, come directly from the sun, but according to another, are photoelectrically liberated in the outer regions of the sunlit part, and are deflected by the field of the earth towards the magnetic poles. It will be seen that all upper atmospheric phenomena, electrical as well as magnetic, can be divided into these two main categories, as shown in the table on the following page.

Terrestrial Magnetism and its variation.

The solar control of the magnetic field of the Earth is illustrated by disturbances of two types—an erratic one called Magnetic Storms, first observed by Celsius in Sweden as early as 1741, who found that the coming of the aurora was heralded by a certain amount of restlessness of the magnetic needle; the Magnetic Storms have since been much studied and have been found, in general, to occur in greater intensity and frequency simultaneously with periods of solar activity indicated by sunspots and aurora. But though correspondence between the two sets of phenomena has been established in a general way, individual correspondence has not been established, i.e., every big spot has not been found to be associated with large scale auroral displays or with large Magnetic Storms.

TABLE.

Sun.	Quiet. (Eleven year Period.)	Active. (Eleven year Period.)	Erratic.	Long Period Variations.
..	..	Spots, Faculæ, Prominences.	Bright Eruptions.	80,000 years.
Total Radiation.	1·92 cal/per cm²/sec.	1·92+·0007 (sunspot no.).	..	..
Optical ..	Luminous Night-sky.	Aurora.	..	..
Magnetic ..	Solar and Lunar Terms in Variation of Terrestrial Magnetic Elements.	Magnetic Storms.	Magnetic pulses.	..
Radio ..	E_1—region, F_1—region (day), F_2—region.	General strengthening of ionization, C, D and other occasional layer formations.	Radio Fade-outs (short and medium waves) strengthening of long wave and Atmospheric reception.	..
Electrical. Lower Atmosphere.	..	..	..	..
Climatic ..	?	?	?	Glacial and Interglacial epochs.

The second type of disturbance of the magnetic needle is of a more regular nature and shows a diurnal and a monthly period. At sunrise, the N.S.P. of the needle is slightly east of its position; at noon, it points approximately to its mean position, towards sunset it moves to the west, and regains the mean position again at midnight.

A Gaussian analysis of these types of disturbances showed that they originate in the Earth's atmosphere and the first explanation was given by Balfour Stewart about 1860, and considerably extended by Schuster. The theory conceives that the daily disturbances are caused by horizontal movements of electric currents in the upper atmosphere across the vertical component of the Earth's magnetic field. The nature of these currents could not be explained at the time, but after the discovery of the electron, they were naturally ascribed to movements of electrons, and detailed theories of daily variation of magnetic elements were worked out by Chapman and others.

The Ionosphere.

The idea that there are charged particles moving in the upper atmosphere was rescued from the cold storage into which it had fallen in a rather romantic way, when Marconi in 1898 succeeded in transmitting electromagnetic waves from England to America. When the result was communicated to the Royal Society, Lord Raleigh very pertinently remarked that the waves could not have travelled in a straight line, as there are hundreds of kilometers of solid obstacle presented by the curvature of the earth when the two stations are connected by a straight line. They must therefore be guided along the surface of the earth, or got reflected from the upper atmosphere. To explain this difficulty, Kennelly and Heaviside almost simultaneously about three years later proposed that the upper atmosphere contains a number of free electrons which form a sort of metallic shield about the earth, reflecting the wireless waves and thus keeping them confined within a narrow shell about the earth.

The prediction was at that time in the nature of speculation but success of wireless propagation and the fact that all other alternative explanations were found either useless or insufficient showed that the hypothesis of the existence of the ionized layers higher up in the sky was one in the right direction. Precise theory has evolved as a result of successful refinements by Eccles, Larmor, Appleton and others. At the present time it is known that the electrons which act as reflectors of the wireless waves are stratified in different layers of which two are permanent. They are known as the E_1 which is at a height of about 100 km., and F_2 discovered by Appleton in 1923, which is at a height of about 200–250 km. Methods have now been perfected for finding out the night and day variation of the heights of these layers, their maximum electron concentration and variation of these quantities during the hours of day and night and also during the whole year. In addition to these permanent layers there are subsidiary ones, of which mention will be made later.

Source of free electrons : Photo-ionization.

We can now ask ourselves about the origin of these electron layers. Here, as in the questions about the origin of the aurora, there were long controversies whether these layers were formed by electrons coming direct from the sun as originally proposed by Birkeland, or were they due to electrons liberated by the ionizing action of ultra-violet sunlight. The question was answered in a decisive way by observations of the density of electrons during the total solar eclipse of 1932. These showed conclusively that at least in the E and F_1-regions the electrons were produced by the ultra-violet sunlight because, during the instant of totality as soon as the light was cut off, the density of electrons fell to a very small value. It is therefore clear that the production of electrons in the E and F_1- regions is entirely controlled by the sun, through its ultra-violet radiation.

A thermo-dynamical theory of ionization of the upper air constituents by the ultra-violet rays of the sun was worked out in a general way six years before the eclipse observations gave a clear reply to the controversy by Prof. Pannekoek of Amsterdam in 1926. In 1931 Prof. Chapman, following an earlier work by Lenard, worked out a *mathematical* theory of the production of electrons by monochromatic light which enabled one to obtain a formula showing the variation of electron concentration with the zenith angle of the sun. We have here the gases constituting the earth's atmosphere, which are being traversed by the rays of the sun at varying angles. The rays produce the dissociation of molecules into atoms, and ions and electrons. But these processes cannot go on unchecked, and the free ions and electrons recombine producing again neutral particles and sometimes the electrons attach themselves to elements having electron affinity and form negative ions.

The general theory of ionization of the atmospheric constituents by sunlight was worked out by Pannekoek by extending the theory of Thermal Ionization given by the present author six years earlier with the aid of a modification proposed by E. A. Milne for the case when the temperature of radiation is very different from that of the gas traversed. Pannekoek calculated the equilibrium number of electrons produced by the sunlight from nitrogen, oxygen and hydrogen molecules making certain plausible assumptions regarding the quantities which are needed for the calculation. These are the ionization potentials of the molecules and the elements, the temperature of the sun regarded as a black body, and the temperature of the upper atmosphere. The values adopted for all these quantities were rather rough, but nothing better could be done at that time. Pannekoek was, however, able to show that the number of electrons obtained from such calculations and the height at which the maximum concentration occurs was in rough agreement with the number obtained from the ionospheric experiments. By 1931 much more was known about the ionosphere, e.g., there was, thanks to the work of Appleton, Nichols and Schelleng, Gilliland and Kirby, precise information regarding variation of the maximum number of electrons in the E and F-layers, during hours of the day, with season and latitude, and to account for these Chapman worked out in greater detail the variation of the number of electrons produced by a monochromatic beam of light when the rays of the sun fall at different slanting angles and was able to show that his conclusions were in substantial agreement with the results just mentioned. Chapman's theory is, however, severely mathematical and he had to assume that the equilibrium is of the uni-component type, that is to say, the electrons are produced from one component, say from the nitrogen or the oxygen molecule or the oxygen atom, and the electron produced combines with the ion of that component alone. But on account of mathematical difficulties the theory, although in a position to explain the results of observations for the E and F-regions roughly, did not enable him to make any calculation of the actual number of electrons produced

as Pannekoek had done. In fact, the two theories existed side by side, and no connection was shown between them.

This fact and the arbitrary assumptions regarding the values of the ionization potentials, and of the values of the absorption coefficients of the photo-ionizing radiation made it extremely desirable that the foundations of both the theories should be further critically examined.

A beginning in this direction has been made by the author and R. N. Rai. It is a re-working of the Pannekoek theory, since they found that the Chapman theory was implicitly contained in the fuller theory of Pannekoek. But they have shown that a satisfactory theory involves accurate knowledge of many factors, such as absorption coefficient, ionization potential, etc. Some of these, e.g. ionization potentials which were roughly known when Pannekoek gave his theory, had been more precisely determined by 1936. But a knowledge of I.P. alone is not sufficient, as information must be available regarding the intensity and variation of the absorption coefficient of these radiations with frequency for atmospheric constituents, atoms or the molecules concerned. The necessity of this was not realized before, but as the height of maximum ion-production varies inversely as τ_0, the maximum absorption coefficient, the importance of determining accurately the nature of $\tau(\nu)$–ν curves becomes apparent.

The previous workers had used for this purpose a formula given by Kramers, which was deduced on the basis of the old quantum theory for explaining the absorption of X-rays by matter. But, as Rosseland remarked, the usefulness of the formula was over-stressed, and even in the case of hydrogen, where it is most expected to hold, Leigh Page has recently found the formula defective. The best course would have been to obtain the nature of $\tau(\nu)$–ν curves from actual laboratory experiments, but obviously such experiments can be carried out only for O_2 and N_2, and it cannot yet be seen how they can be carried out for O and N-atoms. Even in the case of molecules, the experiments are very difficult, and complicated by other phenomena. But such experiments as exist (e.g., those of Hopfield and Takamine) and their theoretical interpretations show that for each of the O_2 and N_2-molecule, two types of ionization exist—first, a feeble one, caused by a forbidden electronic transition, and the second one, caused by an allowed transition. The τ-values for the two processes are entirely of a different order, the second process being at least 10^4-times more intense than the first.

A tentative wave-mechanical theory for photo-ionization of atoms like O and N can be worked with some effort, but it appears wrong to utilize the same or a slightly modified formula for molecular photo-ionization. It is rather surprising that no theory of photo-ionization of molecules has yet been attempted. A beginning in this direction has been made by B. D. Nagchowduri and K. M. Bose for H_2, but the cases of O_2 and N_2 present almost insuperable mathematical difficulties. In this connection it may be noted that the $\tau(\nu)$–ν curve does not begin with a maximum at ν_0, the minimum photo-ionizing

frequency, but is reached at some distance, depending on the values of the nuclear distances of the atom, and the ion respectively. Further, the curve is not smooth like that of the atomic photo-ionization curve, but is broken up at points $\nu = \nu_0 + n\omega$, where ω is the frequency of vibration of the ion, and n is the number denoting the upper harmonic.

It will possibly take some time before such curves, so much necessary for calculating ionization of the upper atmosphere, are accurately determined. It is, however, pleasant to notice that Takamine has already started such experiments, and obtained a certain amount of verification for ionization of the N_2-molecule by neon-light.

Formation of Electron Layers.

An unexpected result, which comes from the revised Pannekoek theory of ionization, is a successful explanation of electron layer formation, which was originally attempted by Lenard and more fully from the mathematical point of view by Chapman. They showed that if *monochromatic light* is absorbed by atmospheric constituents with liberation of electrons, the constituents being assumed to be distributed according to isothermal equilibrium, a layer of electrons is formed in the regions where absorption takes place. The electron-density attains a maximum at a certain level, where the pressure is proportional to Mg/τ_0, and falls off nearly parabolically on both sides. The half width of the layer varies as $\frac{kT}{Mg} = H$, usually known as the height of homogeneous atmosphere. This theory was roughly verified by investigations of the form of the lower side of the E_1-layer and the F_1-layer. It appeared that to explain the form of the E_1-layer, it has to be assumed that H is small, of the order of 10–15 kms., while that of the F_1-layer is about four times as great. These might be ascribed to the fact that the temperature of the F_1-region is, according to some workers, about four times larger than that of the E-region, but if the F_1-region is due to ionization of the oxygen atom, as suggested here, we need not make the temperature four times larger than that of the E-layer. A temperature double that of E would do.

But apart from other difficulties Chapman's work was insufficient in one respect, namely, that it was proved only for monochromatic light, whereas actually if we suppose the sun to be a black body at 6000°K the ionizing radiation should consist of the whole spectrum beginning from a certain limit and extending indefinitely towards the ultra-violet. It could not be seen off hand if ionization by such a spectrum would not destroy much of the properties of the layer. But in the revised theory, it so happens, and it is a rather unexpected result, that even continuous spectrum produces a layer very much similar to the simple one made familiar by the work of Chapman. It must be admitted, however, that the form of the layer depends to some extent on that of the photo-ionizing absorption curve, which is not yet known for the ionization processes

actually occurring in the atmosphere but is only deduced from a plausible theory. As long as this is not known, it is of course not possible to give further precision to the theory, but approximate values of electron concentration can be obtained with the aid of some plausible assumptions regarding the radiation from the sun and the temperature of the Upper Regions.

These considerations, therefore, lead us to the conclusion that the different stable layers as observed in the ionosphere are due to ionization, by the appropriate solar radiation, of distinct constituents of the atmosphere, viz. N_2, O_2, N, O, the maximum of the layer occurring at the height where total absorption of ionizing radiation by the particles reaches its maximum value. We may proceed to identify the processes. The E_1-layer must be due to a process of ionization which is effective only at a height of 100 kms. As the amount of gaseous oxygen and nitrogen molecule above this height is of the order of a few cms., the radiation which causes E-layer ionization should be such that it can be transmitted through a few cms. of nitrogen and oxygen gas at N.T.P. These considerations prove that the E-layer is probably formed by the first process of ionization of O_2 and N_2 at 12·2 and 15·5 volts. The pressure at the apex of the layer is given by $P \simeq \frac{Mg}{\tau}$. Now for an allowed transition, τ_0 is of the order of 3×10^{-17}; for a forbidden transition it may be taken to be 10^4-times smaller, say 10^{-22}. We then get $P = 10^{-2}-10^{-3}$ mm. of mercury. This is just the pressure in the E-layer. The F_2-layer, on the other hand, should be due to ionization by radiation which can be stopped by about a thousandth mm. of the gas, because at a height of 200–250 km., where this layer is formed, the amount of gas lying above cannot exceed this amount. We can easily link up this fact with the second ionization of N_2 and O_2 which gives rise to excited O_2^+ and N_2^+, because the ionization occurs with an intensity which as mentioned before is about 10,000 times stronger than the first ionization. The pressure, calculated from the formula $P \simeq \frac{Mg}{\tau}$ is of the order of 10^{-6} to 10^{-7} mm. which is of the order of pressure at the F-layer. The F_1-layer is a purely daylight phenomenon. It is found that the night F-layer splits up into F_1 and F_2 when the sun is sufficiently high up in the sky and towards nightfall, when the sun's altitude has fallen, F_1 and F_2 unite to form one single layer. The F_1-layer is therefore a purely daylight phenomenon and is probably due to an extra process besides ionization which is operative only during daytime. All the available knowledge supports the view and this has also been mathematically demonstrated by Dr. R. C. Majumdar that during daytime the oxygen molecule probably completely dissociates into atoms at a height of about 200 kms. on account of absorption of radiation between the wavelengths 1750 Å and 1300 Å, a process which has been very thoroughly studied in the laboratory by Ladenburg and Van Voorhis. P, the pressure at which the maximum absorption of this radiation occurs, is of the order of 10^{-4} to 10^{-5} mm. of mercury and hence it is between the E- and F-layers. The electrons which

give rise to the F_1-layer must be due to further ionization of the oxygen atoms, so produced during daytime. At night time or when the sun is sufficiently slanting, probably most of the oxygen atoms at this level would recombine to form molecules and therefore the F_1-layer will disappear, as there are not sufficient oxygen atoms to be ionized.

The F_2-layer.

This explanation may appear to be apparently at variance with certain other observations, for example, the anomalous behaviour of the F_2-layer. It has been already remarked that the formation of the E_1- and F_1-layers follows solar control and it demonstrates approximately the validity of the theory of photo-ionization by sunlight and theory of recombination as in a unicomponent system. The concentration in these layers attain a maximum at about noon and follows the fourth power of the cosine of the sun's zenith angle, a result which can be deduced from these theories. The seasonal variation is also in accordance with the theory of solar control. But not so with the F_2-layer for which maximum concentration is found to occur for Slough in summer at about 9—10 A.M., is followed by a minimum at 2 P.M., followed by a maximum at 8 P.M., and a pronounced minimum at 3 A.M. Even during winter, though a midday maximum is obtained, there is an unaccountable smaller maximum at midnight. For other latitudes as well, the behaviour is anomalous. During total solar eclipses, the F_2-region ionization appears to remain unaffected. All these and other facts show that either the solar control theory is insufficient for this region, or in working out the theory of photo-ionization we should not regard the system to be a unicomponent one. Probably in the F_2-region the pressure is so low that collision between the electrons and ions must be extremely infrequent, and neutralization takes place after intervals of the same order of magnitude as the day: hence the equilibrium theory has probably to be considerably modified.

It must not be supposed that even if we except the highly perplexing features of the F_2-region, the theory of solar control can explain all the characteristics of the ionosphere. Rather puzzling is the persistence of ionization in the E-region at night. According to the solar control theory, the E-region should entirely disappear as soon as light is withdrawn because in this region collision frequency is quite large (10^5 in a sec.) and recombination must be very quick, but we find that there is residual ionization, about 1/20th of the maximum amount, which is present throughout night. It does not appear probable that this is due to positive ions. We must therefore suppose, as Martyn and Pulley have done, that at night there is probably some mechanism at work by which fresh electrons are produced. It is not improbable that a neutral molecule colliding with a negative ion might knock out the electron, and supply the electrons necessary for maintaining the residual E-layer at night.

A complete theory of the various puzzling ionospheric phenomena will probably take years of work. Much depends on the correct interpretation

of the results obtained by the method of reflection of radio waves from the ionosphere. It must not be supposed that the magneto-ionic theory of propagation of e.m. waves which is now holding the field is infallible.

Radio Fade-outs.

Probably the solar control of the upper atmosphere is nowhere more strongly illustrated than in the phenomenon of Radio Fade-outs, which has been studied in recent years as an international programme by a number of workers in Europe and America, particularly by Dellinger in the U.S.A. and Jouast in France. It was observed for some years that sometimes radio signals which were being usually received from a distant station suddenly stop and the normal conditions are obtained after a lapse of time which extends usually over a few minutes. Observations showed that many of these sudden radio fade-outs were simultaneous with the appearance on the surface of the sun of small bright patches of intense white light observed by Carrington as early as 1859. Spectroscopic observations carried out at Mt. Wilson and elsewhere showed that these patches emit the Balmer lines of hydrogen in great strength. From the international programme carried out by Dellinger and Jouast it was found that the phenomenon is confined only over the sunlit part of the globe and the interruptions were simultaneous over different parts of the earth within the sunlit regions, and that the sudden stoppage was connected with intense chromospheric eruptions, though all eruptions did not give rise to radio fade-outs. Further investigations showed that neither the ionization nor the height of the E- and F-layers was very much disturbed during these sudden radio fade-outs. The cause of the disturbance must, therefore, be sought below the E-region or in an intense transitory ionization of the regions below E, which is sometimes called D by Appleton. This is further confirmed by an increase in intensity of long-distance radio by means of very long waves during radio fade-outs, which refer only to short and medium waves, because long waves are reflected from the low, i.e., D-layer. Further, the radio fade-outs are accompanied by magnetic disturbances of short duration, which are strongest over the part of the globe directly under the sun at the time of the eruption. This shows that the small patches send out flares of ultra-violet light which produce intense ionization of the region D.

Let us see how this flare works. The great strengthening of the hydrogen lines is merely a token that something unusual is happening on the sun. Spectroscopy tells us that when the Balmer lines are emitted in great strength, the Lyman lines would in fact be far stronger, but it can be shown that neither the Balmer lines nor the first two Lyman lines can produce any ionization in the atmosphere, because the amount of energy they carry is below the critical limit required for ionizing any of the atmospheric constituents. It is only the third Lyman γ and the subsequent lines which can ionize O_2 to O_2^+ by the first process of ionization which, being feeble, can penetrate to lower levels. This

is also confirmed by the experiment of Takamine and Suga who found that the L_α and L_β lines can be transmitted in undiminished strength through thin columns of O_2, but the slightest trace of O_2 obliterates L_γ. There may be, besides, radiation of other elements of approximately the same wave-length and they will reach the D-level which contains, above itself, nearly 11 cm. of N_2 and 0·57 cm. of O_2 at N.T.P. The above is only a suggestion. The particular part of the solar spectrum which is responsible for the extra ionization in the D-layer will be only found out after extensive research. But the phenomenon illustrates that even transient disturbances on the surface of the sun find their echo on the doings of mankind on the earth, which involve the upper atmosphere.

Tentative theories of the Luminous Night Sky.

We might briefly pass over the problem of the luminous night sky phenomenon, which has been briefly reviewed earlier. There is no difficulty in comprehending that the luminescence of the night sky must be in some way intimately connected with the action of sunlight on the constituents of the Upper Atmosphere. But the great puzzle is the persistence of the phenomenon. Take for example the green line, which is a permanent feature of the night sky. We can suppose that during daytime, photo-electric action of the solar rays decomposes oxygen molecules into normal O atoms and excited O atoms, and the excited ones if they are in the $O'S_0$-state revert back to a lower state giving rise to the green line. It must be added, however, that no such photo-electric phenomenon has yet been discovered. This explanation cannot hold for the night sky emission of the green line, because the life of no excited atom can ever be much larger than a second, and hence as soon as sunlight is withdrawn all metastable oxygen atoms will promptly revert back to the normal state. How does the green line then originate in the night sky? The only explanation which promises a certain amount of success is a theory of recombination between ions and electrons, which must be going on when sunlight is withdrawn from these heights. At daytime in the F-region, illuminated by sunlight the upper atmosphere would consist mainly of electrons and ionized atoms of O and N and probably also of O_2^+ and N_2^+. When sunlight is withdrawn at night, the electrons will combine with the ionized atoms and molecules. To fix our attention, let us take the case of O_+. An electron colliding with it may form oxygen atom in the normal state as well as any one of the two metastable states ($O'S$ or $O'D_2$). The metastable states, after they are formed, will emit the green line or the red line and revert back to the normal state after fraction of a second, because they have nothing else to do. This theory of night sky luminescence recalls to the mind of the author the stimulating theory of Zanstra of emission lines of Planetary Nebulæ, all of which are forbidden lines of the type of the green line. This also explains to some extent the Height-effect of Vegard, who found that the green line is intensified in the higher part of the sky. The explanation is that at the lower parts, the $O'S_0$-

atom will collide with other particles and lose its energy by collisions of the second type before it has a chance to radiate. The emission of the green line is therefore a consequence of recapture of electrons by the O^+-ion, and its persistence is due to infrequency of collisions in this region due to small pressure. It is estimated that at these heights, the mean free path of the electron is extremely large, say about 10^8 cms., and the velocity is probably in the neighbourhood of 10^7. So there may not be more than one collision per second but only one in 10^5 gets captured to form an $O'S_0$, or $O'D_2$-atom. These will then have nothing to do except radiate the green or the red auroral lines. We can by the same hypothesis explain the absence of the negative bands of nitrogen from the night sky spectrum. It is well known that the negative bands arise from an excited state of N_2^+ which however can be produced by direct ionization of normal N_2 by ultra-violet sunlight possessing an energy of the order of about 21 volts. Any excited N_2^+ which is produced in these upper layers must immediately disappear as soon as sunlight is withdrawn, a hypothesis which explains in a convincing way Slipher's observation that during the morning or evening flash of sunlight, the negative bands of nitrogen are obtained from the upper atmosphere in great strength but they disappear as soon as sunlight passes away. At night time therefore the N_2^+ -ion which remains is non-luminous and there can be no further emission of negative bands, unless N_2^+-normal is further activated by electron impact. The electrons will combine with this N_2^+ forming different excited states and immediately after the recombination, the excited N_2 will revert back to the lower states giving rise to the second and first positive bands and the Vegard-Kaplan bands. The persistence of luminosity in the sky throughout the night, therefore, seems to be due to the fact that on account of extreme rarefaction at these heights, the rate of recombination is extremely slow. As a matter of fact even without fresh sunlight, the electrons and free positive ions can probably exist for days together, as is shown by the existence of the F_2-region in the polar atmosphere, even when these regions are perpetually in the dark for days together.

Astrophysical Theories of the Sun.

From the above incomplete review it will be clear that a correct interpretation of the upper atmospheric phenomena suffers greatly from the desiderata that we have no direct knowledge of the ultra-violet part of the solar spectrum as it would appear to an observer outside our own atmosphere. For our purpose, this knowledge is most important because almost all the Upper Air Phenomena are due to the action of ultra-violet light on the constituents of the atmosphere and when a disturbance takes place on the sun, it is the ultra-violet radiation which is most affected. But the question may be asked why not tackle the question from the astrophysical side? As a matter of fact, astrophysicists have not been idle. Mention may be made of a famous paper by Sir A. S. Eddington which aimed at giving a quantitative idea of the formation of

Fraunhofer lines and its subsequent extensions by Milne, Chandrasekhar, Wooley and Strömgren. But if one goes very deeply into the fundamental assumption underlying these works, it is found very difficult to be able to agree with many of their basic assumptions, e.g. there is no reason to suppose that the radiation from all layers of the sun should be black body radiation. In fact, the assumption is positively contradicted by certain observations. If the temperature of the surface of the sun, which gives us the continuous background of light, were 6000°K, it can give us only such absorption lines which require moderate excitation and the chromospheric spectrum would give us emission lines whose excitation potential should not be greater than 6 to 9 volts. But it is a well known fact that the chromospheric spectrum of the sun gives us the lines of helium requiring an excitation potential of over 20 volts and also a line of helium$^+$ ($\lambda = 4686$ Å) which requires an excitation potential of about 79 volts. It is therefore clear that the common notion that the sun radiates like a black body at a temperature of 6000°K can only be an approximation and a very rough approximation indeed. In fact, the Russian observers, Perepelkin and Melnikov, in a publication from the Pulkovo Observatory have shown that the intensity of these emission helium lines is almost nil on the limb of the sun, and gradually rises to a maximum at a height of 2500 km. in the solar atmosphere and then steadily falls. This shows that the mechanism, which is responsible for the emission of these helium lines must be very different from what is associated with a state of black body radiation. We can suppose that the intense ultra-violet radiation from the interior passes through the upper layers of solar gases, produce ionization in these layers and subsequently these ionized electrons and atoms recombine giving rise to the intense helium lines which are observed from the chromospheric spectrum of the sun but are absent from the Fraunhofer spectrum. If the lines of subordinate series to which belong most of the helium lines in the visible and the He^+-line λ 4686Å can come out prominently, it is clear from fundamental consideration of atomic excitation that the line of the fundamental series λ 584 Å due to He, and λ 304Å due to He^+ should come out still more prominently. Thus if we could observe the spectrum of the sun in the ultra-violet region, probably the principal lines of helium, hydrogen and iron$^+$ and many other elements would be obtained as emission lines. But at the present time all theoretical works would be merely speculative. The decisive evidence would be obtained if a spectrum of the sun could be secured at a height of 40–50 km., i.e., considerably above the ozone layer.

The above short review shows that though it is easy to postulate that the atmosphere, upper as well as the lower, is entirely controlled by the sun, it is very difficult to work out the details and present a complete unified theory. For this purpose we must know more about the normal behaviour of the sun, as well as of its abnormal behaviour which is manifested in the form of sun-spots, prominences, faculæ, the small patches of intense light responsible for radio fade-outs. But even this does not appear to be the whole story.

Long Period Variation of the Sun.

In a very thought-provoking paper Sir George Simpson has pointed out that in addition to the short period variation, the sun has also probably a long and somewhat irregular period of variation, extending to about over 80,000 years. He supposes that there is a periodic fluctuation in the amount of radiation which is emitted by the sun. When the amount increased, it caused on the earth intense cloud formation in the equatorial regions, and this, paradoxically enough, caused intense glaciation over the poles. In this way he has been able to explain successfully the occurrence in the Pleistocene age of four successive glacial epochs separated by interglacial ones observed in Europe by Penck and Brückner and connected by the anthropologists with the different cultural epochs of *Homo sapiens*. Possibly the Chellean epoch, when *Homo sapiens* began to make tools and thus lay the foundation of civilization, was started by such a caprice on the part of the sun. It is a thought-provoking idea, but the astronomer has probably no chance of verifying it, as neither he, nor the civilization of which he is a bye-product, can hope to exist for 80,000 years. This short review will, I hope, convince you that the romance of our knowledge of the sun is still in the making.

Symposium on Weather Prediction.

Under the auspices of the National Institute of Sciences of India, a symposium on Weather Prediction was held in the Meteorological Office, Poona, on the 25th and 26th July, 1938, under the presidency of Prof. M. N. Saha, F.R.S. Various aspects of forecasting of weather were discussed at the symposium, attention being focussed in most cases on the problem as it faced the Indian meteorologist and was attempted to be solved by him. Papers presented at the meeting concerned long-range forecasting for a whole season as developed in India, medium-range forecasts for 10-day periods as developed by the German and Russian Schools, short-range, i.e. day-to-day forecasting in India with special reference to the application of air-mass analysis, the use of upper air data for weather forecasts, thermodynamic studies of the atmosphere with special reference to latent instability, rainfall in north-west India associated with winter disturbances, weather forecasting for aviation and the application of kinematical methods to forecasting.

President's Opening Remarks.

Prof. M. N. Saha, President of the National Institute of Sciences of India, in opening the symposium, expressed his thanks to all those who had responded to the invitation of the Institute to take part in the discussion. He referred to the fascination which the art of weather prediction had held out to man from the earliest times, to the development of synoptic weather charts in this country from the time of Blanford and Eliot and to the subsequent contributions made by Indian meteorologists to the art and science of weather prediction, and invited Dr. Normand to open the discussion.

Opening Address, by Dr. C. W. B. Normand, Director-General of Observatories.

Dr. Normand said: This meeting is under the auspices of the National Institute of Sciences but owing to its location here in this office and my association with the India Meteorological Department, I claim the privilege of offering, on behalf of the Meteorological Department, a hearty welcome to all those who have come from a distance to this symposium.

It is a year and a half since the idea of a symposium on Weather Prediction was first mooted. At one time the suggestion was made to include it in the programme of the Indian Science Congress at the Jubilee Session at Calcutta. You, Sir, told me that to the eminent scientists from overseas it ought, at least, to prove amusing. To the eminent scientists, who are here now, let us hope that the discussions that are to follow will be equally amusing—and amusing in the good old-fashioned sense as well as in the modern.

That is, may it make us *muse* over what we hear; may it lead us to ponder upon the difficult scientific problems that a study of weather prediction brings to our notice.

I have one regret about this symposium. There are no principal speakers from outside this department. At one time we had the promise of two from elsewhere, who however have not, in the end, been able to come. To non-members of the Meteorological Department I would point out that here is a monopoly to be broken and the first steps to do so may be taken to-day in such time as our President may allow for remarks and questions and for heckling the principal speakers.

To some people, a symposium on Weather Prediction may require justification. One high official in Government once asked why a meteorological department should exist, when it would be so much cheaper to engage astrologers to forecast weather from the stars. In this symposium you will see there is no speaker down to speak to us on forecasting weather from the stars, for the simple reason that no astrologer has yet shown that his forecasting methods are based on scientific principles or will stand the test of scientific criticism. Every forecaster, amateur or professional or quack, finds some of his forecasts turning out correctly, if he forecasts often enough; and it is a curious fact (which Sir Gilbert Walker pointed out some years ago and many of us here have learned by experience) that 'while the forecasting efforts of charlatans are judged by their occasional successes, it is the occasional failures of a government department which are remembered'.

In this symposium the main speakers start with a creed—a scientific faith—that in weather we see the results of the ordinary laws of physics operating on the ocean of air. They have learned not to be downcast if they cannot trace the physical cause of every connection. Our first speaker, Dr. Savur, will probably tell us that abnormally high pressure in South America in April and May is, more often than not, associated with a strong monsoon in India in June to September. I don't expect him to give you a reason, because I don't think he or anybody else knows. But he can show by means of satisfactory statistical tests that the relationship is real and significant. There must be a physical reason for that particular relationship just as there must be a physical or chemical reason for the 11-year periodicity in sunspots and solar activity. Some people criticise seasonal forecasts on the ground that it is unwise to use a relationship, based on a smallish though significant correlation coefficient, unless you know the physical causes behind the relationship. I personally agree with the other view that if a fact is established with reasonable certainty, we are at liberty to make use of it if we can. For instance, if we could use the solar cycle in weather forecasting, surely we would do so, although no astrophysicist can tell you why there is an 11-year cycle in the sun's activity.

India is the country in which the subject of seasonal forecasting has been most intensively studied. Sir Gilbert Walker carried it farthest, but the whole

problem is so complex, that at the end of it all Sir Gilbert Walker advised the use of the word 'foreshadowing' instead of 'forecasting' in order to remind ourselves and everybody else that the utmost one can do at present is to give a very general indication of the total rainfall over a large area for a period of 2 to 4 months. The details of the fluctuations over the area and through the season cannot be forecast. Hence, we aim in seasonal foreshadowing to issue a statement that is brief, unambitious yet unambiguous in its wording.

The next question for consideration is: can forecasts be given for 10 days ahead with a fair amount of detail? Obviously these would be of great use to many people in business, especially in India's chief industry of agriculture. You will hear to-day of the attempt being made in Germany and Russia to develop this medium-range forecasting. Here again, there are no clear-cut physical causes and effects, but rather an arduous back-breaking task of digging for empirical relationships out of vast heaps of data, with just a few principles to guide one in the search. No intensive study has been undertaken yet in India on this problem. In the U.S.A., it is said that the German methods will be critically examined for the possibilities of their application in America. Meteorologists in London indicate that these methods are not yet thought applicable to British conditions.

When we come to daily weather forecasting—forecasting for a half-day or a day or for two days in advance, we come to an art or a science which has been practised for sixty years or more in many countries. We must start with some postulate. So we start with this: that if you have to forecast to-morrow's or the next day's weather in the Deccan you must know *now* what today's weather is both over the Deccan and over surrounding regions as well, because in 24 hours' time part or even the whole of the air now over the Deccan will have moved elsewhere. So, we postulate an up-to-the-minute weather map for diagnosis of the present situation. From diagnosis we have to pass to the next stage of prognosis or prediction. What principle, what methods have we to use in this step?

The ideal method is obvious enough. You write out the complete dynamical and thermodynamical equations, enter the numerical values that represent to-day's situation, solve the equations and derive the subsequent weather sequence as a function of time. Needless to say, the atmosphere is very much too complex to be dealt with in this manner. The only real attempt to follow this method was that by L. F. Richardson in his book 'Weather Prediction' published in 1922. He entered the discrete elements of present data,—simplified the different equations where he thought it justifiable to do so,—and solved them by the method of finite differences. The calculation is lengthy and cannot be finished by an ordinary staff of computers until some days after the period of forecast is over. Also, at the end of that long calculation, the answer may not be right! Yet Richardson's attempt, if it was a failure from the practical forecaster's point of view, was a glorious failure—the like

of which any of us would be proud to be able to accomplish. Amongst other things, it reminds us that a method to be successful in practice must be capable of giving the answer quickly. The essential elements have to be selected, analysed, and combined into a picture of the future within an interval of half to one hour.

An alternative method to Richardon's is to apply mathematics or graphical methods to a selected body of the data. Thus Bjerknes, at one time, proposed the careful preparation of each day's *stream lines* and the careful examination of the *kinematics* of the air flow. By that means he hoped to be able to map out the areas of divergence and convergence. And let me warn you that you may hear much about divergence and convergence from subsequent speakers. The reason is this. The vertical movements are the important ones in producing weather. Rain is always preceded by upward movements,—and places of upward movement appear on the surface charts as areas of convergence. Now Bjerknes' method of stream lines has never been followed up with accuracy on a large scale, because of the difficulties of getting sufficient, accurate data of wind. When tested intensively over a small area in Norway in 1917-18, it led however to far-reaching results, which I shall mention in a minute or two.

There are other mathematical treatments available. For example, the isobars or isotherms or any other isopleths may be treated as a function of time. Knowing the change of pressure since 12 or 6 hours ago, along with the further special information about the tendency of that change in the past hour or two, you can imagine that for each station you have pressure described as a function of position and time. Imagine the function to be continuous and you then calculate what the isobaric field should be 6 hours later. Quick methods of calculation have been devised. Later on Dr. S. K. Banerji will tell us how they can be applied in meteorological practice.

Of course having only the picture of the field of pressure for 6 hours ahead is not sufficient. We have to guess also the kind of weather that will be associated with it. That guess is generally partly empirical and partly physical. The empirical method is, I may remind you, eminently practical. You notice the pattern of isobars on your latest weather map. You also have beside you a catalogue of past isobaric patterns (as a policeman would of finger prints). You look out those most similar to the isobars of to-day, and further weed out the selection by making not only isobars but also isotherms and other elements agree. You are then left (you hope) with a past example of what is happening now and you forecast that what happened after that last example will happen again. A great deal of daily forecasting is still done on that principle. The complete list of past years' charts may never have been catalogued in a form for publication, but the experienced forecaster carries the memory of past weather maps in his head and is undoubtedly greatly influenced by them.

Why doesn't this practical, empirical method suffice? For one thing it is more difficult to find a repetition of exactly the same situation in weather

than it is in a deal of bridge hands. More important still, our knowledge of the simultaneous upper air humidities and temperatures is so meagre that you simply do not know which of all the past maps is the best likeness.

Let me mention just one more general method, one that has been developed out of Bjerknes' original suggestion of drawing the stream lines. His intensive study of stream lines in Norway had forced attention to discontinuities in the general flow—and these discontinuities or 'fronts' came to be recognized as the boundaries of more or less homogeneous air-masses; and finally attention became particularly focussed on the identification of air-masses themselves. The idea is briefly this. At this moment monsoon air is flowing over the Western Ghats and its properties are fairly homogeneous day after day from Mangalore to Bombay. At Quetta, however, and in Baluchistan generally, the air has quite different properties, being drier and warmer, because it has had a different history and comes from a quite different source. So you can divide a bit of your map into areas of fresh monsoon air and of continental air, and you go on to picture how, according to simple physical laws, these homogeneous air-masses should interact at their boundaries and behave within themselves. This whole question of air-masses, their recognition, their behaviour, is a very live one just now amongst meteorologists. It invites approach from several aspects, and is a hopeful method of analysis, especially for the *present-day* requirements which demand attention to detail. At one time the practical forecaster could devote most of his time to consideration of rainfall. Now airmen want forecasts of upper winds, of height of cloud, of fog, duststorms, sudden squalls. There is this variety of requirements and yet the decisions of the forecaster have to be made in quick time; there is no opportunity for lengthy calculation. The symposium will show how these problems are being approached.

SEASONAL FORECASTING IN INDIA.

By S. R. SAVUR, *Meteorological Office, Poona.*

(*Read at Symposium, July 25-26, 1938.*)

Introduction.—India is one of the few countries in the world which depends almost entirely upon agriculture for its prosperity. Agriculture, in its turn, is dependent upon rain, which should be sufficient and well distributed. Hence it is but natural that from time immemorial, Indian agriculturists should have tried to read signs in the sky with a view to discover the nature of the ensuing rains. Many of their observations have come down to us in the form of sayings, some of which show the extraordinary insight some of our forefathers possessed in interpreting meteorological phenomena.[1] Coming to recent times, H. F. Blanford [2] made the remarkable discovery that late and heavy snowfall in the Himalayas is prejudicial to the June–September rainfall in India. This observation has been made use of from the very beginning in the seasonal forecasts issued by the India Meteorological Department. In this note we shall trace the growth of this branch of Indian Meteorology from its origin to the present day.

Forecasts of meteorological phenomena can be divided into two classes, *viz.*, short range forecasts and long range forecasts. Short range forecasts are usually limited to a period of 24 hours, but on rare occasions they extend to over 48 hours or a little more. Long range forecasts, as attempted in this country, are for periods ranging from two months to four months. Since these periods cover definite seasons, these long range forecasts are also called seasonal forecasts.

Historical.—H. F. Blanford was appointed Meteorological Reporter to the Government of India in 1875. From 1882 to 1884 he made attempts to estimate the prospects of monsoon rains. In 1885 it was decided that a monsoon forecast should thenceforward be given annually. The first of the regular series was given on the 4th June 1886. It has been continued till now.

The first forecast was mainly based on snowfall in the Himalayas and the Sulaiman range during the preceding January to May and on the mean pressure over Bombay. The next year Sir John Eliot added conditions over the whole of India, and a year later in 1888 he took into consideration the conditions over the Bay of Bengal and the Arabian Sea.

In 1888 and 1889 the monsoon memorandum was issued in two parts:—the preliminary memorandum in the third week of May and the final memorandum about the 9th of June. From 1890 onwards the preliminary portion was dropped out. The memorandum which began with 3 pages swelled in 1892 to 22 pages.

In that year an additional forecast for August-September was given. This too has been continued till today.

In December 1893 the first forecast of winter rains in northern and central India during January–March 1894 was given. This also has been continued till now.

Since the monsoon winds come from the Indian Ocean, Eliot added in 1896 what he called 'the local peculiarities' there, namely the south-east trades at Mauritius, Zanzibar and Seychelles. In 1897 he added data of South Australia and the Cape Colony. As it included a detailed discussion of these factors, the memorandum had swelled to 44 pages by 1900. In that year 'Nile flood' was used as a factor. It was believed that 'low Nile' meant 'famine year' in India.

In 1904 Sir Gilbert T. Walker gave his first forecast, namely that for June–September rainfall. He soon found that periodicities did not pay. We now know why periodicities are not useful. This point will be discussed later on.

The method used by Eliot to discover whether a factor had any influence on the rainfall in India was by drawing a graph for that factor and seeing whether it showed any parallelism with the graph of subsequent Indian rainfall. This method has much individual bias. Walker supplanted this method by the correlation method developed by Karl Pearson and his school. This new method not only eliminated personal bias to a very large extent but simplified the selection of factors considerably. In 1907 a forecast formula was calculated, but in that year and the next, this formula was used more or less as a guide to the inferences drawn in the old manner. In 1909 the first forecast using a regression equation was made. From this year onwards the memoranda gradually diminished in size.

In 1906 was started the publication of memoranda comparing the forecasts with the actuals. These have been continued to this date.

The winter forecast, which used to be given in December till then, was given early in January in 1913, because some of the data on which it was based could not be had before the end of December. This practice has been continued till now.

Walker realized that India, being more or less a continent by itself, cannot be considered as one homogeneous unit regarding the distribution of rainfall. In 1914 he used the method of correlation to divide India into fairly homogeneous groups and selected the following four areas:—Burma, north-east India, south Madras, and the rest called 'India main'. These divisions were used from 1916 onwards till 1924 with slight variations.

In 1924, just before he retired, Walker divided India into three groups called the Peninsula, north-east India and north-west India. These are in use at present. He also selected 28 factors out of a large number after applying a test discovered by him in 1913 and which is now known as 'Walker's test'. Using these factors he worked out 6 forecasting formulæ.

These formulæ were in use till 1930 when they were revised using the same factors * but including all the data up to 1930.[8] An examination of the results showed that almost all the factors had diminished apparently in significance to a greater or less extent, but the most remarkable thing was that not more than 7 factors out of 28 had become quite insignificant, a fine testimony to the keen insight of Sir Gilbert Walker. The tests that had been applied were those in current use at that time. These tests are really only applicable to cases in which the factors have been selected at random, but not to a case where a choice has been exercised in the selection of factors. Still one had to be content with those tests as no better tests were then thought of.

The late Mr. J. H. Field, who succeeded Sir Gilbert Walker in 1924, suggested in 1923 the use of upper air data at Agra during September and October as a factor for the January–March rainfall in north-west India; the data of 10 years, available then, had yielded a correlation coefficient of $0{\cdot}91 \pm 0{\cdot}04$. Walker, who also had this factor in mind as long back as 1917, did not accept this correlation coefficient at its face value, probably because a selection of the period was made after the examination of a number of coefficients, this selection increasing the probable error of the coefficient to an extent that could not be easily determined. Mr. Field also must have shared this view as he did not make use of this factor during his period of Director-Generalship, although the possibility of the use of that factor continued to be pointed out every year.

By this time the length of the memoranda had been cut down very much, the length varying from 1 to 8 pages. This decrease in length was possible because the use of the regression equation did not call for any lengthy description of the influence of the various factors. Since 1927, when Dr. C. W. B. Normand succeeded Mr. Field, the length of the memoranda has been cut down to 2 pages. Only on very rare occasions has the memorandum covered two and a half pages.

Seasonal forecasts are always somewhat vague. Prior to 1931 they were of the type 'Rainfall is not likely to be far from normal' or 'Rainfall is likely to be normal or in slight excess'. To the initiated the word 'normal' meant an interval of 20% on either side of the average. In 1930 tables were computed with the idea of issuing slightly more definite forecasts, more definite in the sense of our being able to judge after the event whether they were right or wrong. These tables were ready early in 1931 and were used in drawing up forecasts from June 1931.

Three years previously, in 1928, Walker had suggested that no forecasts should be given which have less than an 80% chance of success. This very reasonable suggestion has been generally followed in the issue of all forecasts since January 1932.

---

* For factors now in use, see Appendix I.

In October 1931 Dr. Normand began the use of a general test called by him 'The Performance Test', which eliminated the personal element inherent in the old method of selecting factors. This test has helped us in the following ways:—

(1) To test the significance of the factors,
(2) to test the significance of the regression equations,
(3) to select significant factors to replace the insignificant factors, and
(4) to arrange the factors in the order of reliability.

Naturally it took some time before all the above possibilities of this test were grasped. This test has been in use since January 1932. It was only when this test corroborated the significance of upper-air data in forecasting winter precipitation in north-west India, that that factor was incorporated in the forecasting formula from 1935.

Some elementary theoretical considerations.—Objections have been raised off and on against the application of correlation methods to weather prediction. The main objection is that we are using factors only on the strength of the value of their correlation coefficients with our forecasted element although there do not appear to be any physical reasons for a relation between them. This objection is not so formidable as it appears and has been partly answered by the researches of Sir Gilbert Walker [4] on world weather, but the greatest argument in favour of the correlation method lies in the accuracy of the results as will be seen later on.

Suppose a quantity X depends upon other quantities Y, Z, ... etc. Then if we denote amounts by small letters we can write

$$x=\phi(y, z, \quad . \quad . \quad . \quad . \quad) \quad \text{where } \phi \text{ is some unknown function.}$$

To a first approximation, we may take ϕ to be a linear function. We thus get

$$x=k_1 y+k_2 z+ \quad . \quad . \quad . \quad . \quad .$$

where k_1, k_2 . . . etc. are constants, and x, y, z, etc. are departures from their respective population means.

This is the assumption with which Sir Gilbert Walker started his series of papers in which correlation methods were applied to weather prediction.

If X, Y, Z, etc. are distributed normally, the linear relation between them follows at once. There is reason to believe that this assumption may not be far wrong in the case of the factors used in seasonal forecasts.

Now, we do not know all the factors that affect our forecasted element, X. We may therefore write

$$x=\alpha+\beta$$

where α=total contribution due to known factors and β that due to other independent factors.

Since more than 60 corresponding values of x and α are known we may take the observed values of the standard deviations of x and α and of the

correlation coefficient between them as not far from their true (population) values.

If we measure x and α from their respective sample means, which are very nearly equal to their respective population means, we see that the mean of the β population is zero. We thus know the distribution of β completely and so can find out the limits beyond which the chance of a value of β occurring is less than an assigned quantity. The calculation of such limits is very much simplified if use is made of the tables computed by S. R. Savur and S. Gopal Rau.[5]

Suppose with 20% as the value of chance, the limits are $\pm\beta_1$. Then the chance of a value of β occurring between $\pm\beta_1$ is clearly 80%. Similarly with 40% as the value of chance let the limits be $\pm\beta_2$. Then the chance is 20% for the occurrence of a value of β greater than $+\beta_2$ or for the occurrence of a value β less than $-\beta_2$.

Suppose in a year the value of α is α_1. Then we can give one of the following three forecasts, each of which has an 80% chance of success:—

(1) x will lie between $\alpha_1-\beta_1$ and $\alpha_1+\beta_1$.

(2) x will be less than $\alpha_1+\beta_2$.

(3) x will be more than $\alpha_1-\beta_2$.

The selection of one of these forecasts, assuming that the forecaster wants a *forecast having an* 80% *chance of success*, is, from the point of view of theory, immaterial. However, certain other considerations have been used by Dr. Normand in the selection of the particular type of forecast in any year. They are briefly the following.

From a knowledge of the distribution of x alone, *i.e.* without using any forecasting formula, we can calculate the chance of success of each of the above forecasts. This chance has been termed by Dr. Normand 'the intelligent layman's chance of success'. One of the criteria adopted by Dr. Normand is that the forecaster's chance of success should be appreciably greater than the layman's chance of success of the same forecast. Otherwise the forecast is not useful. This is the criterion that should be satisfied by all forecasts before their issue is considered.

Forecast (1) is preferred when $\alpha_1=0$ or a small positive or negative quantity, forecast (2) when $\alpha_1+\beta_2$ is either zero or negative, and forecast (3) when $\alpha_1-\beta_2$ is an appreciable negative quantity. It is no wonder that with such restrictions there have been occasions when no useful forecast could be given. Since June 1931, when the Performance Test began to be used, to the end of January 1938, only 5 out of a possible number, 38, of forecasts were not issued, this small fraction, about $\frac{1}{8}$, being, no doubt, due to a lucky chance. Ordinarily one might expect to find such occasions on about $\frac{1}{5}$ or $\frac{1}{4}$ of the total number.

As a typical example of the method used in forecasting we may consider the August-September forecast for the year 1936.

For the *Peninsula*, the calculated departure of rainfall from normal came out to be $+1{\cdot}7$.

(A) 80% chance of success forecast based on the above is 'That rainfall will not be below 94% of the average'.

(B) 80% chance of success forecast made by an intelligent layman is 'That rainfall will not fall below 80% of the average.'

Now the random chance of success of the forecast (A) is only 60%, which is much below 80%. Again (A) is very different from (B).

Hence both the criteria are satisfied and it was therefore decided to issue a forecast.

In a similar manner, it was also decided to issue a forecast for *North-West India*. The full wording of the forecast was:

> 'The monsoon rainfall of August and September will not be less than 94% of the average in the Peninsula nor less than 83% of the average in North-West India.'

Actually the rainfall was 92% of the average in the Peninsula and 104% in North-West India, showing that while our forecast in respect of North-West India was successful, that for the Peninsula was wrong although by a narrow margin of 2%.

Justification of the method employed.—We have said already that one of the best proofs of the utility of any method is in the accuracy of the results predicted from it. Let us apply this test to our method.

Out of 33 forecasts given so far (January 1938) since June 1931, 27 forecasts were not wrong, and the ratio of 27 to 33 exceeds slightly the 80% expected. To find out the significance of this result we may proceed as follows. While the average chance of success of these forecasts according to the formulæ is 78%, the intelligent layman's chance of success is only 64%. The probability of obtaining not more than 6 failures in 33 forecasts on the intelligent layman's chance of success is 2%, showing that the chance of only 6 failures out of 33 would have been small for the layman.

The probability for the same event on the forecaster's chance as calculated from the formulæ is 39%, showing that the actual success is within the limits of variation due to random chance. Hence the formulæ have performed up to expectation.

We have said that the correlation methods are strictly applicable when all the quantities are distributed normally in their respective populations. The quantities that we have been using for our forecasts are mean monthly pressures, mean monthly temperatures and total rainfall amounts over one or more months. It is only in the case of rainfall that one might expect a big departure from normality of distribution. This view is no doubt true in the case of the rainfall at a single station, especially if the station is situated in an arid or semi-arid tract. But when the rainfall is taken over a large area like north-west India, the Peninsula or north-east India, and over a period of

wo or more months, the distribution is likely to tend towards normality. This point was tested in 1933 by D. Sankaranarayanan [6] who found that there was no appreciable departure from normality in the case of the rainfall data used by us in our forecasts. This may be considered a further justification of the methods used in our seasonal forecasts.

Taking all these into account we see that, although the correlation method may not be ideal for forecasting work, yet it is sufficiently good to yield results having significance. Hence it is proposed to continue this method until a better method is devised.

Sunspots and periodicities.—It has been said previously that Sir Gilbert Walker did not put much faith in sunspots or other periodicities. With regard to sunspots he showed in 1915 that their influence could not be considered significant. The question of periodicities was examined by S. R. Savur in 1927 and again in 1935.[7] It was found that periodicities were of little or no use for the drawing up of useful forecasts in India. In fact, no proof has been found anywhere for the belief that weather repeats itself at regular intervals.

A few shortcomings.—It is fully realized that the kinds of forecast issued now are far from perfect. They are given for big areas and for periods ranging from two to four months, that is to say they do not indicate any local variation or distribution from month to month or from fortnight to fortnight of rainfall. These defects, although not small, are not as serious as one might at first imagine.

Let us first take the local variation in the seasonal rainfall in any big area, say the Peninsula. The smaller areas, which are political divisions, such as Gujarat, the Konkan, etc., included under this big area, are such that the rainfall amounts in the smaller areas have tolerably high correlation coefficients between one another. This means that the local variation, that is the variation from one small area to another, is not much.

The variation from month to month of the average rainfall is already known. When we had in any year an excess in the total rainfall during, say June–September, it is found that there was in a majority of cases more than average rainfall in each of the four months, although not by the same proportionate amount. A similar remark holds good in the case of years of deficient rainfall. Hence the drawback in giving the forecast for the whole season instead of for the individual months is not very serious.

Attempts are being made to overcome these defects gradually. The first improvement will be the issue of forecasts for smaller areas than are in use at present. Some groupings of areas have been tentatively made and are being tested by the Performance Test. If the result of the test is favourable the smaller groups will be adopted. Only after this question is settled, will the forecasting over smaller intervals of time be taken up.

It has been said earlier that the method of correlation is strictly applicable only when all the quantities that are correlated are distributed normally.

Although the departure from normality has not been found significant, yet one cannot assert that the quantities are distributed normally. If therefore there is a departure from normality, it is difficult to see to what extent the correlation methods are reliable. However, to overcome this defect some general methods are being developed which are applicable to all cases irrespective of the frequency distributions. Although the theory is still in its infancy, it is hoped that ere long it will have been developed to such an extent as to be capable of useful application to seasonal forecasting.

It has been said above that attempts are being made to diminish the period over which the seasonal forecast is issued. On the other side, an effort is made to lengthen the period over which the day to day weather forecast (short-range forecast) is made. Is it possible to bridge this gap? In this connection it should be noted that the method used in seasonal forecasting is quite different from that employed in short-range forecasting. The former may be termed 'statistical method' and the latter 'dynamical method' in that the latter makes use of what is known as 'frontal' analysis. At present 'frontal' analysis is not expected to yield useful forecasts beyond about two days, whereas the 'statistical' method of seasonal forecasting is not used at present for a period of less than about two months. One would imagine that a judicial combination of the two methods might enable us to give forecasts for periods of fifteen days or less, which are short from the point of view of seasonal forecasting but long from the daily forecasting view point. That roughly is the method employed by Franz Baur in Germany since 1932 for his forecasts over 10-day periods. The reason why a period of ten days was selected by Baur appears to be that the variation during a month of, say, temperature is likely to be big, whereas in a small period like 10 days only small variations may in general be expected. Hence Baur considers that forecasts over a period of ten days are more useful than over a month.

It will not be necessary to describe the actual method used by Baur, but the forecasts were stated in somewhat general terms, though it must be added that the latest forecasts (see sample at the end) are more definite than the earlier ones. Baur says that during the years 1932–1936, the percentages of success were 68, 81, 84, 87, and 84 respectively.

In this connection it is interesting to note that C. E. P. Brooks suggested in 1926 the use of mean monthly anomalies of pressure to forecast the subsequent movement of 'centres of excess or centres of defect' of pressure. After applying the method he found that 'we should expect a reasonable amount of success in spring but doubtful results during other seasons. Evidently some improvement in the methods is required before long-range forecasting from the movements of centres of pressure deviation can promise success'. So far, no improvement appears to have been suggested.

In applying methods of correlation to forecasts over periods of as short as 10 days or so, there is a pitfall which is not easily recognized but which

should be avoided. Correlation methods should be applied only to those cases in which the frequency distribution is either normal or not significantly different from normal. It is well known that the day to day variation of a meteorological element over a single place is generally far from normal, while the variation of the mean of the same element over a number of days departs less and less from normal as the number of days, over which the mean is taken, is increased. The departure from normal becomes less marked when a big area instead of a single station is considered. Hence before applying correlation methods it appears necessary to test whether the element, the value of which is to be forecasted, is distributed in a form which is not significantly different from normal. Unfortunately this test appears to have been overlooked in a number of cases where correlation methods have been applied.

In conclusion it may be said that efforts are being made to give seasonal forecasts over smaller areas than those in use at present and also for periods shorter than those over which seasonal forecasts are given at present. Whenever any method for this purpose is discovered, its efficiency can be quickly judged by the Performance Test so that it can be decided quickly whether the method can be adopted immediately. Appended below is a table giving the various factors used in foreshadowing Indian rainfall in the different seasons, which may be found interesting even by the general reader.

References.

[1] Ganganatha Jha, Meteorology in Ancient India, *Allahabad Univ. Stud.*, *1*, pp. 1–11, (1925).

[2] *Rep. Adm. Met. Dept. India*, 1882-83, pp. 4 sqq.; *Proc. Roy. Soc. Lond.*, *37*, pp. 3–21, (1884).

[3] *Ind. Met. Dep. Sci. Notes*, *4*, No. 37, (1931).

[4] *Mem. Ind. Met. Dep.*, *20*, pt. 6; *21*, pts. 2, 9–12; *23*, pt. 2; *24*, pts. 4, 9-10. *Mem. Roy. Met. Soc. Lond.*, Nos. 17, 24, 36, 39.

[5] *Ind. Met. Dep. Sci. Notes*, *5*, No. 49, (1932).

[6] *Ind. Met. Dep. Sci. Notes*, *5*, No. 55, (1933).

[7] *Proc. Ind. Acad. Sci.*, *2*, pp. 336–341, (1935).

Appendix I.

*Table giving the factors used in Indian seasonal forecasts.**

Division.	Factors used.				
			June to September.		
Peninsula R = ·63.	Java rain (Oct.–Feb.)	South America pressure. (Apr. and May.)	South Rhodesia rain. (Oct.–Apr.)	Dutch Harbour temperature. (Dec.–Apr.)	
N.-W. India R = ·64.	Equatorial pressure, from Zanzibar to Port Darwin. (Jan.–May.)	South America pressure. (Apr. and (May.)	Dutch Harbour temperature. (Mar. and (Apr.)	South Rhodesia rain. (Oct.–Apr.).	Snowfall accumulation on the western Himalayas. (May.)
			August and September.		
Peninsula R = ·64.	Mauritius pressure. (July.)	Local pressure. (July.)	Java rain. (Oct.–Feb.)	South Rhodesia rain. (Oct.–Apr.)	
N.-W. India R = ·64.	Mauritius pressure. (July.)	South America pressure. (June and July.)	Local pressure. (July.)	South Rhodesia rain. (Oct.–Apr.)	
			January to March.		
N.-W. India R = ·72.	South America pressure. (December.)	Western rain, from Persia to Baluchistan and Kashmir. (December.)	Port Blair rain. (December.)	Seychelles pressure. (Nov. and December.)	Agra west upper winds at 5–8 Kms. (Sep.-Oct.)

R = Total correlation coefficient of the forecasting formula.

* Savur, S. R., *Ind. Met. Dep. Sci. Notes*, *4*, No. 37, (1931).

Appendix 2.

Ten-day forecast by F. Baur.

(Translation.)

15th Forecast for 1937—Forecast of weather in general for the period 16th–25th September, 1937, issued on the evening of 15th September, 1937.

'Unsettled, frequently windy, weather with changing cloudiness and frequent rain is to be expected in the next 5–7 days. The temperatures will oscillate, but will for the most part be below the normal of the season. It is only in East Prussia that the average temperature of the coming 10 days will perhaps be nearly normal. The day temperatures will only seldom, and in some places only, rise above 20°. The nights also will be often cool, though frost need not be feared in the plains or in East Prussia.

In the course of the next week after the temporary increase of the unsettled character of the weather a change of the general weather situation will probably take place; hence towards the end of the period to which the forecast applies, more settled weather with decrease of rain will set in.

Duration of sunshine in the ten-day period will not in general exceed 50 hours.'

Discussion.

Mr. V. Doraiswamy Iyer.—The desire to foreshadow the monsoon, so important to India, has been in existence for a very long time, even in ancient India, and an attempt in this direction is indicated by some observations of Varahamihira on the relation between conditions of the winter sky and the rainfall of the subsequent monsoon.

The fact that India is the only country where long-range forecasting or foreshadowing has been practised regularly for a long number of years is due to the circumstance that India is one of the few countries where the seasons, especially the monsoon, set in with almost clockwork regularity in the beginning of June. Other countries which have a similar monsoonal regime also lend themselves to a similar foreshadowing, and the speaker has derived a foreshadowing formula for the monsoon rainfall of Upper Siam.* Some attempts are also being made in China in this direction.

Among the attempts to foreshadow rainfall for smaller regions of India should be mentioned the work now being done by the speaker and Mr. Seshachar to foreshadow the monsoon rainfall of the Maidan and Malnad portions of Mysore separately.

We have so far attempted only to foreshadow the total rainfall of the monsoon or of the latter half of the monsoon season. We have yet to make an attempt to foreshadow the date of onset of the monsoon to help the agriculturist in his tilling of the soil and sowing; we have also to make an attempt to foreshadow the periods of breaks as well as periods of excessive rainfall

* *Ind. Met. Dep. Sci. Notes*, *4*, No. 38, (1931).

during the monsoon season, by making a more intensive study of the pulses in the monsoon.

It should also be mentioned that the factors used in foreshadowing the monsoon rainfall of India have their basis on large scale relationships of the seasonal weather in different parts of the globe, although the relationship cannot be directly traced in some cases. Thus South American pressure which plays so important a part in all forecasting formulæ of Indian rainfall does so by its being a member of the 'Southern Oscillation'.

MEDIUM-RANGE WEATHER FORECASTS.

By S. Basu, *Upper Air Observatory, Agra.*

(*Read at Symposium, July 25-26, 1938.*)

I. Franz Baur's forecasts for 10-day periods.[1]

1. *Introduction.*—The National Institute for working out scientific methods of long-range forecasts, founded in 1929 and now attached to the German Meteorological Service, first started working with the problem of forecasts for a month; this period was chosen because the monthly meteorological means were available already worked out for many stations. It was soon found, however, that very few practically useful and reliable forecasts could be issued by working with monthly averages. Weekly forecasts were next tried; but after some preliminary studies it was decided that the choice of 10-day periods was more workable for medium-range weather forecasting.

2. *The Basis of Work.*—The 10-day forecasts which were first published in the summer of 1932 are based on a combination of statistics and synoptics; accordingly the process of preparing the forecasts is divided into two entirely distinct parts.

For the statistical study of weather history it is assumed that over a wide region the weather of the next 10 days is essentially determined by the sequence of atmospheric events in the preceding 10 days. The validity of this hypothesis can only be tested by trial; and the results of the forecasts are claimed to have demonstrated the general correctness of the assumption.

The second part of the work consists of the study and analysis of synoptic weather charts of the fore-decade and the post-decade with due consideration to the 'broad weather situation' of the day on which the forecast is to be made. The term 'broad weather situation' requires definition. It is a condition of the atmosphere which controls the weather for several days, remaining sensibly unchanged during the period which includes a series of individual weathers. The assumption that the direction and strength of the pressure gradient aloft determine the general weather affords the starting hypothesis.

3. *The Reality of Broad Weather Conditions.*—The observations made since Dines' important paper[2] of 1912 have confirmed the existence of a relation between pressure in the upper levels and the air temperature below. In 1922 Mahalanobis[3] showed that the relations with the conditions at 4 km. were closer than those found by Dines with the conditions at 9 km. Thus the pressure gradients in the lower stratosphere and the temperature gradients in most of the troposphere tend to be related. Working with the direction of motion of regions of rise and fall of pressure (isallobars), the Frankfurt

school found that, for the 24-hourly changes at ground-level, the control by the pressure (isobars) at 5 km. is very complete; this control has been called by them 'steering'. (Four types of steering, viz., Northerly-, Easterly-, Trough- and Double-steering were illustrated by slides.)

From figures given by Baur (figs. 1–4, pp. 244-245, *Met. Zts.*, Band 53, Heft 7, July 1936) we see that the motion of the pressure changes at sea-level undergoes steering by the pressure at 5 km.; further, fig. 5 shows that the regions of high pressure at 5 km. are also regions of large vertical heights between the 1000 and 500 mb. isobaric surfaces which are therefore regions of high temperature in the lowest 5 km. The use of the 5 km. pressure as a substitute for the pressure in the stratosphere does not hold when the pressure gradient in the lower stratosphere is feeble, with the winds in the stratosphere and the upper troposphere essentially different. This is illustrated in the case of the double-steering. Baur accepts that lows are due to waves on a surface of discontinuity and remarks that double-steering can only be explained by supposing that waves develop in the tropopause or the equatorial front as well as on the polar front. That these examples of steering are representative may be inferred from the fact that during the 15 periods of the first three months of 1935, in 14 cases the steering obeyed the rule, while in the remaining case there was no direction of motion. Examination of cases throughout 1935 and 1936, Baur states, bears out the same conclusion. His experience of these steerings is:—

1. The mean duration of a *broad* weather situation is 5½ days.
2. On an average there are, in Central Europe, 5 of these situations in a month, the intermediate days being transitional.
3. The longest durations are of West-steering when Central Europe is under a region of high pressure in the stratosphere and is therefore not crossed by areas of rise and fall of pressure.
4. The most frequent directions of steering are W (18%), NW and SW (each 17%), quite rare SE and very rare NE and E.

Since the pressure gradient in the lower stratosphere, the average gradient of temperature in the troposphere, the general flow and the steering fit together and last for some days, it is reasonable to regard them as constituting the broad weather situation. In working out these medium-range forecasts, the formation and breaking up of stratospheric highs and lows replaces the probem of the surface highs and lows in daily weather work. It must not, however, be concluded that because these are determinative of the broad weather conditions they are the primary cause of the weather itself.

4. *The Statistical Foundation.*—The statistical work consists of computing correlations, the choice of the elements and interpretation of the results being based on physical-meteorological considerations. Till now, the statistical foundations for the three July decades and the three August decades have been worked out from 40 years' observations from 1893–1932. The data used for

this purpose are the pressure and temperature values for 26 stations extending from Greenland to Kiev and Vardo to Algiers; in addition, the pressures at certain points at sea were also used. To allow for short-period oscillations, five-day means of observations were utilized.

To include the totality of all cases, overlapping means were used. Thus, for example, for the second decade of July the working out of correlations did not stop with correlating the data for 1–10th July or the changes between the mean values for 1–5th and 6–10th July with the data for 11–20th July; but in addition to these the corresponding pairs of values for June 26–July 5th and July 6–15th, June 27–July 6th and July 7–16th, etc., were correlated with July 5–14th and July 15–25th. So that 400 pairs of values were obtained for each decade out of the 40 years' observations (440 pairs for the decades with 11 days).

Correlations were worked out for the following factors:—

Pre-decade.

1. Mean pressure.
2. Change of pressure, i.e., the difference between the mean pressures of the first and the last five days.
3. Change of temperature.
4. Change of pressure from the fifth to the tenth day.
5. Inter-diurnal variability of pressure in the last six days.
6. Pressure on the last morning (sample day).

Post-decade (the period of forecast).

1. Mean pressure at Potsdam (near Berlin).
2. Mean pressure at Oslo.
3. Mean pressure at Treuburg (north-east of Germany).
4. Frequency of precipitation in north Germany west of the Oder.
5. Frequency of precipitation in south Germany (computed from the data of several stations).

The coefficients by themselves give no useful indication of pressure, but gave values up to $-0{\cdot}4$ for rainfall.

The computed values of the coefficients for all the 26 stations were then plotted on charts. Baur states that, for the physical meaning of the statistical result, the change in the aspect of the correlation picture (the shifting of the centre of the greater positive or negative correlation from decade to decade) is very important. Without discussing this aspect in detail, however, he merely mentions that the correlation pictures change from decade to decade in a very appreciable manner (as seen from figs. 1–3, p. 152, *Bull. Am. Met. Soc.*, Vol. 17, No. 5, May 1936); except that for all the summer decades the correlations with the pressure distribution on the last day of the fore-decade gave almost the same picture (e.g., for rainfall, illustrated in fig. 4) which repeats in the other July and August decades.

The next step was the computation of combined correlations in which the values for the fore-decades for several stations were joined together by addition or subtraction. Those combined quantities which were recognized

as factors indicating the future weather were finally entered in multiple correlation tables with one of the elements of the weather to follow. Such multiple correlation tables, mostly with four variants of the fore-weather, were computed —eight for each decade. The values of the multiple correlations computed so far range up to 0·82 to 0·89.

The multiple correlation tables also form the basis of comparison between the broad weather situation of the forecast-day with other analogous situations. By means of the simple device of attaching the date of each event noted in the multiple correlation table, one can immediately search out all the events in which the variables had about the same values as on the forecast day. Unfortunately, Baur has not explained more fully, nor illustrated by any example, the multiple correlation table with all the entries. Hence an account of this important step has to remain rather sketchy.

5. *Synoptic Considerations.*—In order to make a more detailed comparison of these in certain respects similar events with the general weather situation in hand, charts and tables of the fore-weather and of the post-weather are made out for each single sample day. Thus for each single day of the six decades of July and August for 4 years (2480 days) the following sets of maps and tables (2480 sets in all) are arranged for purposes of comparison:—

For fore-decades in the Greater European Region.

1. Map of the mean departure of pressure from normal.
2. Map of the change in the mean pressure from the first to the second pentad.
3. Map of the change in the mid-day temperature from the first to the second pentad.
4. Map of the change in pressure in the last five days.
5. Map of inter-diurnal variability of pressure in the last 6 days.
6. Map of the distribution of pressure on the morning of the last day.

For post-decade in Germany.

1. Map of the mean departure of pressure from normal for the first pentad.
2. Map for the mean departure of pressure from normal for the second pentad.
3. Map of the mean departure from normal of the daily mean temperature of the first pentad.
4. Map of the mean departure from normal of the daily mean temperature of the second pentad.
5. Tables of the synoptic air mass types prevailing on each of the 10 days at Karlsruhe (in the south-west), Potsdam and Treuburg (in the north-east).
6. Table of the daily maximum temperature at characteristic stations.
7. Table of the daily duration of sunshine at characteristic stations.

8. Table of the daily precipitation at 30 evenly distributed characteristic stations.

The above statements of the fore-weather and the post-weather corresponding to the 2480 sample days are arranged chronologically in suitable files so that they can be easily referred to for purposes of comparison.

6. *The Forecasts.*—On the morning of the day on which the forecast is to be issued the necessary observational data are collected and, by the collaboration of four persons, the six charts of the fore-weather are completed by 1 p.m. By this time the combined variabilities have also been worked out for the multiple correlation tables. Thus a rough idea is obtained of the character of the weather to follow in the next decade by determining the mathematical expectation of the average pressure of the post-decade at Potsdam, Treuburg and Oslo, and also of the frequency of precipitation in north Germany west of the Oder and in south Germany.

Now with the help of the multiple correlation tables all instances with similar advance weather are isolated, and each of these single instances compared with the advance weather of the day of forecast; those cases which are not wholly comparable are rejected. Then, as a rule, there remain two or three cases in which all the six charts of the fore-weather show, more or less, pictures similar to the situation in hand. The ten weather maps of the post-decade corresponding to the similar instances thus picked out are then studied in all their detail, and synoptically analysed for judging as to which of these possible developments of weather has the greatest probability of following the general weather situation in hand.

In addition, other points are considered. For example, any rhythms appearing in the march of the meteorological elements up to the forecast day are followed up and the possibility of extrapolation is given due weight; also, the pressure distribution at 5 km. or its change, from the observations of the weather airplanes, is studied. In this way, in close connection with the statistical inference, a broad picture of the synoptic weather situation and of the expected weather is obtained. While this process seems very elaborate, in comparison to which the issue of the monsoon forecasts in India is simplicity itself according to Sir Gilbert Walker, the 10-day forecasts are, nevertheless, issued by 6 p.m. of the forecast day.

7. *An Example.*—An example of the predictions for the third July decade of 1935 is given below:—

> 'The fair prevailingly dry weather of the previous week changed on the 15th to somewhat unsettled weather, but nevertheless on the whole the weather, especially in south Germany, retained a friendly aspect.
>
> 'This not unfriendly but, on the other hand, also not fully settled weather with alternate clearing and short, partly thundery, rains will

continue for the next few days. Then in the west and in south Germany for a few days prevailingly clear and dry weather will come, while in north Germany, especially in the coast region and east Prussia, a slight changeableness will remain. Following that, over the whole country there probably will be another cooling and strongly unsettled weather with frequent precipitation due to arrival of maritime and polar maritime air currents.

'In the first half of the last third of July the temperature as the result of a sharp change will come to have a practically normal mean. In the second half on the whole it will be cooler than normal. The number of days with precipitation in the last third of July in central north Germany and east Prussia will exceed 5 in most places though on many days the showers will be merely insignificant. The duration of sunshine in south Germany in the 11 days will exceed 70 hours.'

The above forecast materialised fairly well, although the number of rainy days in central north Germany in many places was only 5 instead of more than 5. Especially striking was the arrival of the forecasted cooling from maritime and polar maritime air for the second half of the decade. The statements in the above forecast by no means lack definiteness; the percentage or correctness in the statements that can be definitely verified in the forecasts of the last five years is said to have been 68, 81, 80, 87, and 84. There even seems to be independent evidence of a higher proportion of successes in Baur's forecasts, which seem to have won a reputation throughout the German State.

8. *Concluding Remarks.*—The methods of medium-range forecasting developed by Baur suggest that a search in India for suitable correlation factors on somewhat similar lines may also lead to fruitful results. *A priori* it would seem that the general considerations for believing in the reality of broad weather situations may also have some validity for general weather conditions in this country. If, therefore, aerological data of pressure and temperature were to be available for the upper levels in India, a study might be undertaken to find out whether any steering rules exist in the case of weather in this country; and if they do exist, to what extent modifications are required to be introduced in them. For this purpose it would be necessary to make a choice of stations for establishing significant relationships, the choice being based on our existing knowledge of physical and statistical meteorology. No doubt, the daily weather forecasting sections and the climatological and statistical sections could make effective joint efforts in this direction. Dynamic climatology based on air-mass analysis would be a requisite for actually applying the forecasting methods outlined above, and it is gratifying to see that the India Meteorological Department has already given attention to this aspect of climatological work. After the preliminary investigations and the spade work are gone through, it would be possible to obtain a more definite

idea regarding the applicability or otherwise of Baur's methods of forecasting for periods of 10 days to Indian conditions.

II. Forecasts for periods by the Russian School.[4]

1. *Introduction.*—At the Institute of Long-range Weather Forecasts, established in 1912 at the Central Geophysical Observatory in Russia, B. P. Multanovsky, the present head of the Institute, was entrusted with the development of long-range forecasting methods. The first attempt at such forecasting was made in 1915 for the Kara Sea region in connection with the work of freeing an expedition held up by ice, and the attempt proved highly successful. From 1919, forecasts for 10–14 days to 2–3 months began to be issued, at first irregularly and then, from 1920, regularly as an experimental measure. From 1922 they were issued by the authority of the Central Geophysical Observatory and, in time, they proved so successful that in 1930 the Institute of Long-range Forecasting was made a full-fledged division of the Central Weather Bureau of the U.S.S.R. Since 1932 long-range forecasts are being issued regularly extending for longer periods in advance, sometimes for as much as 5 months ahead.

Inasmuch as the development of a synoptic process, which is a function of a number of weather factors, varies with the season, the period for which the forecast is issued is not determined by any calendar periods or seasons, but by the period which marks the type of the synoptic process involved.

2. *The Basic Principles.*—The Multanovsky school utilised all the forms of analysis available for examining synoptic situations, viz., statistical, kinematical and dynamical methods. Their method can be best named as the 'Composite Map' method. *It differs from most of the other time-space* correlation long-range forecasting methods and is based on classical synoptic considerations.

Disregarding the prevalent notion that the weather moves from west to east along with the general circulation, Multanovsky started on the assumption that the weather is made, at least in part, in the north sub-polar regions where strong accumulations of heavy cold air are to be met with. For reasons not yet completely understood, lumps or masses of air separate from these regions every now and then. If the places from which these air-masses or 'tongues' of cold air start and the paths along which they travel could be determined, perhaps conclusions regarding the weather in the adjoining regions could also be drawn.

When Multanovsky began his work 25 years ago, the changes in the subpolar regions could only be judged, owing to the lack of direct observational data therefrom, by indirect methods. Therefore, the classification of trajectories of areas of high and low pressures was looked upon as a possible method of attacking the problem. Detailed work showed, however, that, ***in general***, the pressure minima or maxima change paths so often and their variations

are so great that a consideration of mean paths gave no hopeful results. It then occurred to him that the complexity exhibited by the trajectories of pressure systems even for a single season might perhaps be due to the fact that they represent trajectories of pressure systems of different origins; and that *if grouped according to their origin*, the picture might become simpler. Another original idea was to restrict the choice of the trajectories to those of pressure maxima, on the ground that the central part of a high forms the nucleus of pressure; so that the trajectory of the maximum can be taken, as a first approximation, as the trajectory of the nucleus or, in other words, as the trajectory of the air-masses. No doubt at the base of this choice was the prevalent idea that an anticyclone directs the weather in general.

In grouping the trajectories according to their origin, Multanovsky started from the following consideration: all pressure maxima which enter Europe move from the west with the general circulation, provided there is no intrusion of nuclei of high pressure from the sub-polar regions. The effect of such an intrusion is to endow the direction of the high with a meridional component. It was also found that some of the trajectories had a component directed from east to west, i.e. opposite to the prevailing circulation. He thus obtained three groups of trajectories of pressure maxima: (1) directed from the west, from the region of the Azores straight to the east—called the 'Azores normal' type; (2) directed from the north-west quadrant—called the 'normal polar' type; and (3) directed from the north-east quadrant—called the 'ultra polar' type. An average axis called a 'median' or 'normal' was determined for each of the above three groups from an examination of many years' records.

It was found that some of the axes are characterised by great stability and the movement of an anticyclone along a single axis often continues for a long time. The positions of axes over certain regions call for completely determined types of weather in corresponding regions; so that a frequent repetition of the same type of weather gives a definite climatic stamp to that region. The axis should therefore reflect the actual weather conditions occurring in that region. Evidence of this fact is afforded by the distribution of the tree-types over the various regions in Central Europe and western Russia. (This was illustrated by the two maps for summer and winter.)

Now, the passage of a pressure maximum along an axis is bound up with a definite distribution of pressure centres over a large operating area, making the process complicated. However, it is this complexity which makes it possible to appreciate a series of very important situations, provided that the map includes the entire operating area. (An operating area or natural region is defined as a region which includes the entire system of axes taking part in the establishment of the weather over that region.)

To depict the distribution of all the subsidiary pressure areas during the movement of a pressure maximum along a definite axis, the subsidiary areas of high and low pressure (the crests of secondary high pressure areas and

troughs of secondary low pressure areas) are entered symbolically on the map showing the movement of the main pressure maximum. The maps are also illustrated with the corresponding distribution of temperature, precipitation and wind. The maps obtained in this way are called 'Composite Maps' and retain all the details of the life-history of the pressure regions. Multanovsky's investigations have claimed to show that the pressure fields and the axes are closely connected with each other; so that with the aid of the axes one can determine the distribution of pressure-fields and, conversely, a change in the orientation of the trajectory can be determined from the distribution of the pressure-fields.

The time interval which characterises the weather type and during which the pressure centres continue to be situated in separate closed-in regions forming definitely marked pressure-fields is called the 'natural period'. This is the statistical criterion of a natural period; kinematically expressed, there is no intersection of trajectories during such a period. Thus it is seen that an operation along any definite axis continues for 10–12 days, the so-called natural period. The orientation of the process becomes apparent from the initial direction of the trajectory of the anticyclone and from the composite map of the associated pressure distribution during the initial stage of travel of the anticyclone. Hence two or three days after the beginning of a new period (as soon as the orientation of the process becomes apparent) it is possible to determine the weather for the next 7–10 days.

Experience is said to have shown that a phenomenon or process materialises within a period not exceeding 30–35 days after the appearance of a certain significant change—a sort of 'flaring up' of a new process, a 'threatening situation' or simply a 'threat'. Within this time interval one can distinguish approximately five more 'moments'. The pressure distribution corresponding to these moments represents the 'phases' of the development which culminates in the investigated weather phenomenon or leads to a 'development' along an axis having a definite direction. The first of the moments is called the 'threat symptom'.

The length of a phase ranges from 6–15 days, there being 4-5 phases to the period of 30–35 days. The determination of phases for various phenomena is rendered difficult because one must not expect only such situations whereby from the day of threat to the day of occurrence of the event itself one should have the phases of only one given series. What ordinarily happens is that sometime during the development of the process there appears a new threat of the same event, and hence a new series has to be noted. Thus during a season a certain event may repeat itself six to eight times; such combination made the investigation more difficult. The principle of identification of phases and threatening moments associated with them has been applied in a number of investigations of various phenomena. A systematic introduction of phases in forecasting practice, beginning with 1925, has somewhat widened the scope of the forecasts for the periods.

With regard to the question as to where the indicated phenomenon is likely to occur, one should expect that the region where an event is to occur would be subject to a definite set of recognisable changes. According to Multanovsky the most pronounced indication appears on the 13th-14th day after the appearance of the threatening nucleus, i.e. in the third phase. It has not been made clear, however, as to what form exactly these indications take. The day on which is indicated the region where an event is to occur is called the 'regional day'. It is said, for example, that the isobar and isotherm of the *regional* day mark 'sometimes very accurately' the boundaries of the district where glaze is to occur. No further clarification by way of illustration is, however, available.

4. *An Example.*—A typical monthly forecast includes first a long enough discussion of the probable movements of areas of high and low pressures over Europe and the adjoining territories for the period in question; then the general weather characteristics are indicated. All dates are pointed out as precisely as permissible, the margin of tolerance allowed being ± 2 days.

Part of the forecast for August 1935:—

Region (1). *Northern area.*

Period August 2–8. Unsettled weather; cloudiness decreasing towards end of period, then clear . . . passing rains . . . winds fresh to moderate in the beginning of period, then decreasing . . . temperature 16° to 7° rising towards end (temperatures are given for morning observations).

Period August 16–22. First half, varying cloudiness without rain; great increase in cloudiness in the second half of the period; rains light to moderate; temperature range 14 to 7 degrees.

Then come forecasts for the other districts ranging in number from 40–80 depending upon the circumstances allowing greater or lesser number of divisions to be dealt with for the particular period.

A systematic verification of the forecasts was made in 1931 by G. Wangenheim who examined 178 long-range forecasts issued during 1928–1930. It appeared that the forecasts covering natural periods gave as much as 80% verification for precipitation, 75% for temperature and 67% for the combination of the two. He also found that 'forced' forecasts, that is, not for the natural periods but for specified calendar periods, gave a much lower verification.

5. *Conclusion.*—From what idea the above sketchy account gives us of Multanovsky's methods of forecasts for periods, it seems that there are obvious difficulties in attempting to apply them to conditions in India, or for that matter in any tropical country. Because, in these latitudes, anticyclones are never such well-defined entities as in Europe; so that to trace the movement of their centres would lead to very doubtful results. To group together trajectories of such indefinite systems therefore one should have to contend

with very unsystematic and haphazard results. On the other hand, the low pressure systems are quite well-defined and their paths too can be handled with much more exactitude in general. Groups of cyclone-paths are already exhibited in Eliot's Climatological Atlas of India. While it may be possible to foresee a certain type of weather to be operative over the region near the probable located path of a low pressure area on our Indian weather charts, yet it is doubtful if the grouped axes of the trajectories of lows are likely to be useful in developing a method of long-range forecasting on the lines of the Russian school, for the cyclonic fields have been handled by Multanovsky and definitely abandoned as unyielding of valid results, although the European cyclones are as well-defined entities as they are in the tropics.

REFERENCES.

[1] Baur, F.—Grosswetterforschung und longfristige Witterungsvorhersage, *Unsere Welt*, Godesberg, *26*, 1934, pp. 114–120; Entwicklung und gegenwärtiger Stand der Grosswetterforschung, *Die Sterne*, Leipzig, 1935, pp. 145–155; Einführung in die Grosswetterforschung, *Math. Phys. Bibliothek*, No. 88, Leipzig, 1937.

[2] *Geophys. Mem. Lond.*, *1*, No. 2, (1912).

[3] *Mem. Ind. Met. Dep.*, *24*, Pt. 1, (1923).

[4] Multanovsky, B.P.—The present status of development of long-range weather forecasting methods in U.S.S.R., *Met. Messenger*, *43*, 1933, pp. 129–143; Schell, I. I.—A preliminary summary of the Multanovski school of long-range weather forecasting, *Trans. Amer. Geophys. Union*, 1936, pp. 141–152.

DISCUSSION.

Dr. L. A. Ramdas: I wish to supplement Mr. Basu's description of the work done on medium-range forecasts in Germany and Russia, by drawing attention to work done in India during the past few years by the Agricultural Meteorology Section at Poona. The forecasting of maximum and minimum temperatures by using statistical methods was the problem first attempted, as farmers and agricultural research workers were interested in such forecasts. Kalamkar [1] found that during the clear season at Poona the mean daily maximum temperatures of successive months during a series of years were highly correlated (e.g. October-November, November-December, December-January). During these months it was found possible to express the mean daily maximum temperature of a week as a function of the mean maximum temperatures of the preceding four weeks; it was convenient to use these relationships for the prediction of maximum temperatures in different weeks of the clear season. In his next paper [2] Kalamkar worked out the intermonthly correlations for

[1] A statistical study of the maximum temperatures at Poona, by R. J. Kalamkar, *Ind. Met. Dep. Sci. Notes*, Vol. V, No. 59, pp. 133–139.

[2] A study of correlation coefficients of mean maximum temperatures between successive months at a few selected stations in India, by R. J. Kalamkar, *Ind. Met. Dep. Sci. Notes*, Vol. VII, No. 70, pp. 15–19.

successive months, throughout the year, for about 20 representative stations in India. This investigation showed that stations with high intermonthly correlations group themselves in an interesting manner; the centres of high correlation showing a definite movement with the march of the seasons. The centre of high correlation is strong and lies over South India during winter; it is feeble and is over Sind and adjoining areas in North-West India during the south-west monsoon. Over the rest of the country the correlations increase slightly during clear weather and decrease to low values during the wet months. The movement of the centre of high correlation appears to be associated with the movement of the sub-tropical belt of high pressure which exists in the upper levels between 2 km. and 4 km. The results obtained show that the forecasting of maximum temperatures by means of the statistical methods employed would be possible only for the seasons and for the areas with high intermonthly correlation coefficients. The ideal condition for the high association of the climates of neighbouring months is the persistence of clear skies, feeble air movements and the absence of precipitation. Under these conditions insolation has full sway and the accumulation of heat is localised.

With regard to the prediction of minimum temperatures Narasimhan and Ramdas [1] have shown that the minimum temperature during a clear day in winter may be expressed as a linear function of the maximum temperature and the vapour pressure of the preceding afternoon. Forecasting formulæ using the above relation have been worked out for about 20 representative stations in India. The investigations referred to above represent some of the work already done in India on the prediction of specified meteorological elements by means of purely statistical methods. The work is being continued.

Dr. Savur: F. Baur's ten-day forecasts are somewhat vague. As an example, his forecast for the period 16th to 25th September, 1937, may be considered (see Appendix 2 to my paper). Hence it is not easy to judge to what extent the forecast has come out successful.

Again, a selection of factors out of a large number has been made. It has not been stated whether suitable tests like Walker's test or Normand's Performance-test were applied. This is quite an important point.

In any case, I agree with Mr. Basu that Herr Baur's method is worth a trial here.

Dr. Banerji: How is the success of a forecast, which involves a large number of elements, determined when some of the elements turn out to be correct and the others wrong?

---

[1] Agricultural Meteorology: The prediction of the minimum temperature on clear days at selected stations in India, by M. Narasimhan and L. A. Ramdas, *Ind. Journ. Agric. Sci.*, Vol. VII, part V, October 1937, pp. 746–761; see also an earlier article on 'Correlation between frost and preceding meteorological conditions' by Barkat Ali and Naqvi, *Ind. Jour. Agric. Sci.*, Vol. I, part VI, December 1931.

Mr. Basu: With regard to Dr. Savur's question, I quite agree that in the sample quoted by him there is some amount of indefiniteness. But I don't think that any method will, for some time to come, ensure that every forecast issued will be equally definite and precise. It may be possible to be very definite on some occasions and not so precise on others. But certainly the German forecasts do attempt to localise the predicted occurrences in time and space whenever this is warranted. As regards Dr. Banerji's question, I may say that each region is to be taken into account with regard to each forecasted element in judging the verification or otherwise of the forecast issued before the average is worked out.

President: It is not clear why F. Baur chose 10 days as the forecasting period. The methods are interesting, although very complicated, and should be tried in India.

AIR-MASS ANALYSIS AND SHORT PERIOD WEATHER FORECASTING IN INDIA.

By S. N. Sen *and* H. R. Puri, *Meteorological Office, Poona.*

(Read at Symposium, July 25-26, 1938.)

The air-masses.—In the absence, so far, of synoptic observations of pressure, temperature and humidity at different levels of the atmosphere, our ideas of the main properties and thermodynamical peculiarities of the interacting air-masses, as well as our daily forecasts of weather over India, must necessarily be based solely on the available surface and pilot balloon observations, although the results of occasional sounding balloon and aeroplane ascents made at a few stations can subsequently be referred to for further verification.

In classifying the air-masses over the Indian region one would, at first sight, like to recognise simply two main divisions, *viz.*, the 'dry' and the 'moist' air-masses. As a matter of fact, in a country like India, a line of discontinuity at the surface outside winter may be expected generally to be between dry air on one side and moist air on the other. For greater precision in forecasting, however, a further sorting is found necessary. A summary of the detailed analysis is given in the following table, which modifies [1] previous classifications.

The three primary air-masses have some outstanding characteristics. As borne out by the results of the available meteorograph ascents, at any rate in the lower layers, the tropical [2] air has the highest dry bulb temperature, the extra-tropical, the lowest dry bulb and the equatorial, the highest wet bulb. The lapse rate of temperature, on the average, is of the order 7-8° C/km. in the extra-tropical and the tropical and 4-5° C/km. in the equatorial below the freezing level [3]. The moist transitional has also a fairly low temperature lapse rate (5-6° C/km.), which is, however, confined to the bottom layer in autumn and winter, extending upwards by degrees later. In this connection, it may be explained that, compared to the equatorial, the tropical, much warmer at the surface, must, by virtue of its high lapse rate, become colder above a certain level, which will be referred to later as the 'differential level', the height of which increases as the season changes from winter to summer. Above this level, the tropical would therefore behave like the extra-tropical and present

---

[1] In Fig. 2, facing p. 594 of '*Science and Culture*' for June 1937, 'Equatorial South-easterlies' were named 'Tropical Currents'.

[2] Simulation of the tropical and the extra-tropical currents in juxtaposition in the morning appears to be induced by the large diurnal ranges of temperature of the former, originating at the surface.

[3] Over India the height of the freezing level is of the order of 4-5 km. above mean sea level all the year round (as found from results of sounding balloon ascents).

TABLE I.

Classification of the Indian Air-Masses.

Air-Mass.	Source.	Entry into the Indian region.	Character.	Season of dominance in the Indian area.
I. Extra Tropical.— (a) Western Himalayan.	Central Asia and Europe.	Across the Frontier and western Himalayas.	Polar Continental.	Winter.
(b) Eastern Himalayan.	Central Asia, Tibet and China (occasionally also adjoining seas).	Across Tibet, Assam, Burma (by subsidence).	Polar Continental. (Occasionally Polar Maritime).	Periodically between February and June and during the monsoon.
Dry Transitional.	North Arabian Sea; Indian deserts (formed locally).	West coast.	Hot Continental.	Summer and periodically during post-monsoon months.
II. Tropical.— Westerly Drift.	North Africa, Arabia, Iran.	Across the Frontier and Gujarat, Sind and along the west coast.	Hot Continental.	Summer and periodically during post-monsoon months.
Moist Transitional.	Perhaps restricted to north of the equator.	South Arabian Sea.	Continental Maritime.	Periodically during the summer and the monsoon seasons.
III. Equatorial.— (a) South-easterlies.	Equatorial belt.	Across Burma and Tenasserim.	Continental Maritime.	Retreating south-west monsoon period, winter and summer.
(b) South-west monsoon.	Southern hemisphere.	Across south Indian Ocean.	Polar Maritime.	Monsoon season.

a more or less typical cold front to the equatorial, while, underneath, it would lie on a slope of the equatorial, with the withdrawal of which it would simply subside and become heated further.

Seasonal growth of the air-masses.—For a fuller appreciation of the forecasting problem, a knowledge of the usual evolution of the various air-masses in each season is necessary and an indication has already been given in Table I. The three principal air-masses, *viz.*, the extra-tropical, the tropical and the equatorial are, to varying extents, present all the year round within the limits of the region shown in the present weather charts of the India Meteorological Department.

The main extra-tropical stream comes through Iran, Afghanistan and Baluchistan. Since, on the north and north-west, high mountain ranges separate India from the rest of the Asian continent, the flow of this air into the country cannot take place in an unobstructed manner. It has to pass over mountains and come down the slopes by katabatic process or descend from levels above the level of the mountains by subsidence in the widest sense. The subsiding air will apparently get mixed with the already existing air at lower levels by turbulence, while the cold air flowing down the hills will suffer a marked surface heating in the course of its further progress through the country. It is thus obvious that the air in the surface layers can rarely be as cold in the interior of the country as in the sub-Himalayan regions.

As summer advances, the tropical air-mass gradually grows, subsequently to be invaded by the equatorial. Accordingly, by the time of the onset of the monsoon the tropical becomes dominant up to great heights over practically the whole of western and upper India, while the equatorial south-easterlies take possession of the Bay of Bengal. No data of the average rate of growth of the tropical air-mass are available. The following table may however be indirectly helpful in this connection. The data illustrate the seasonal lifting and lowering of a level of stratification.

TABLE II.

Layers at which changes of lapse rate of temperature occur most frequently. (Meteorograph ascents at Agra, published in the India Meteorological Department 'Upper Air Data', 1929 to 1931.)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Height in km. above M.S.L.	1·2	1·2	3·4	4·5	5·6	4·5	3·4	3·4	3·4	3·4	2·3	1·2

An indication regarding the seasonal growth of the equatorial upwards has already been given elsewhere.[1] From the following table of normal vapour

[1] See p. 363 and Table XII of 'Himalayan Meteorology', by Sen and Chatterjee, (Chapter 9 of 'Everest 1933', by Hugh Ruttledge, London, 1934).

pressure gradients at the surface across the various coastal districts, a rough idea may be obtained of the increasing intensity of the convergence of the moist and dry currents, at any rate in a shallow layer above the ground, between winter and summer.

TABLE III.

Horizontal Gradient of Vapour Pressure across the Coast, mb/100 km. (Eliot's Climatological Atlas of India—Plates 76 to 87).

Coast.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Coromandal	1·8	2·0	3·4	3·0	3·0	1·8	1·6	1·2	1·5	2·6	1·8	2·2
Circars ..	1·3	1·8	3·0	3·8	3·9	1·1	0·4	0·4	0·6	1·8	2·2	1·5
Orissa ..	2·5	2·9	4·2	4·9	4·9	1·8	0	0	1·1	1·9	2·6	1·8
Bengal ..	1·2	2·3	2·6	2·8	1·6	0	0	0	0	0	1·7	1·1
Kathiawar	2·5	3·2	5·6	6·6	3·2	3·5	1·8	1·9	2·5	4·2	4·2	2·0

Similar data for layers aloft are not yet available. In any case the table shows how the surface gradients weaken with the gradual breakdown of the dominance of the tropical air-mass inland. By the beginning of June, some parts, *e.g.*, Bengal and neighbourhood [1], come wholly within one homogeneous equatorial air-mass and the vapour pressure gradient across the coast vanishes for all practical purposes. A corresponding premature loss of identity of the tropical air-mass over north-west and central India is prevented mainly by three factors, *viz.*, an intermittent arrival of fresh cold air at the upper levels followed by subsidence or mixing with the lower tropical air, periodic horizontal transport of fresh supplies of heated air across Iran and Baluchistan and surface heating of the lower layers over India. The role played by the tropical air in the mechanism of the Indian weather, as an intermediary between the equatorial and the extra-tropical, is obviously an important one [2].

Development of heterogeneity in air-masses.—It is interesting to note that appreciable heterogeneity is introduced—

(i) into the tropical air by the arrival of fresh cold air at high levels and its consequences;

(ii) into the equatorial, by a horizontal transport of fresh monsoon air into the old monsoon air.

The addition of new masses in the field would modify the stream lines and consequently the discontinuities. It is therefore important to obtain an idea of the nature of relevant 'cold waves' aloft, which are often preceded by 'heat waves'. An example of a heat wave, followed by a cold wave, is shown by the figures in Table IV.

[1] Burma seems to have its own appropriate tropical air-mass.

[2] A dominance of this mass beyond June may cause a failure of the monsoon.

TABLE IV.

Upper air temperatures over Agra associated with western disturbances.

29th April to 14th May, 1931.

(*'Upper Air Data'*, 1931, part 14, pp. 139–142.)

Height gkm.	Heat wave.						Cold wave.		Magnitude.	
	1	2	3	4	5	6	7	8	9	10
	29th Apr. °A	30th Apr. °A	1st May. °A	2nd May. °A	4th May. °A	7th May. °A	8th May. °A	14th May. °A	Heat wave °C (6-1)	Cold wave °C (8-6)
10·0	232·5	230·5	232·0	232·0	235·5	236·0	234·5	236·0	+3·5	0·0
9·0	242·0	240·0	240·5	241·0	242·0	244·5	241·0	240·0	+2·5	− 4·5
8·0	249·5	249·0	249·0	249·0	250·0	251·0	247·5	247·5	+1·5	− 3·5
7·0	257·5	256·0	257·0	256·0	258·5	260·0	256·0	254·0	+2·5	− 6·0
6·0	264·5	263·5	263·0	264·0	265·5	267·5	264·0	259·5	+3·0	− 8·0
5·0	272·0	270·0	272·0	269·0	270·0	271·0	269·5	267·0	−1·0	− 4·0
4·0	279·0	278·0	279·0	277·0	278·5	280·0	278·5	274·0	+1·0	− 6·0
3·0	286·0	286·0	286·0	286·5	287·5	288·5	286·5	281·0	+2·5	− 7·5
2·5	289·0	290·5	291·0	291·0	292·5	292·5	292·0	284·5	+3·5	− 8·0
2·0	293·0	295·0	295·5	296·0	297·0	297·5	296·0	289·0	+4·5	− 8·5
1·5	297·5	300·0	301·0	300·0	302·0	302·5	300·0	293·5	+5·0	− 9·0
1·0	302·0	304·0	305·5	304·5	306·5	307·0	304·0	297·0	+5·0	−10.0
0·5	307·0	309·0	—	309·0	311·0	311·5	—	301·5	+4·5	−10·0
Surface	310·5	312·0	312·5	313·5	314·0	314·0	310·0	305·0	+3·5	− 9·0

It is interesting to note that the fall of temperature due to the 'cold wave' was more than twice the rise of temperature due to the 'heat wave'. In favourable circumstances, such as those governing the fall of rain through a tropical air column in the post-monsoon months, even pseudo cold front phenomena may extend down to the surface [1].

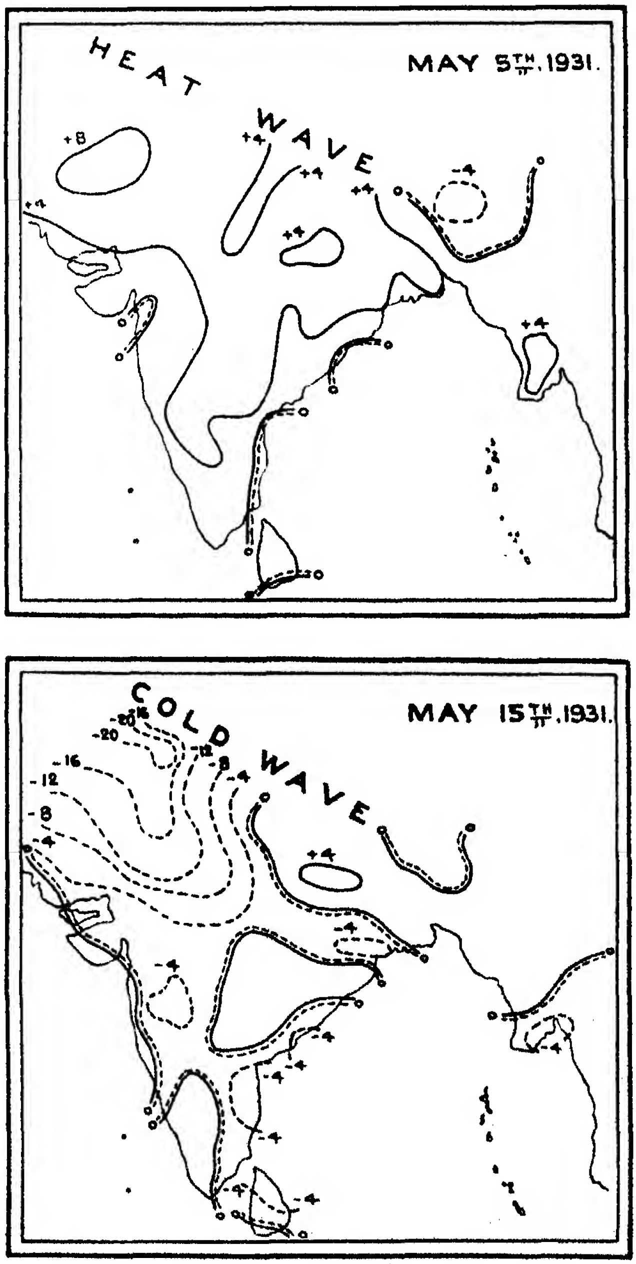
The heat and cold waves at the surface are usually built up by the passage of one or more western disturbances. In the instance examined, the heat wave was most marked at the surface on the 5th May, 1931 and the corresponding cold wave on the 15th May (see Fig. 1).

In the transition months, the subsidence of the extra-tropical and the consequent heterogeneity of the prevalent tropical over western India can obviously reach quite low levels, while on the eastern side, the development of a 'cushion' of the equatorial air inhibits the process, the extra-tropical possibly spreading out laterally. In the circumstances, if the moist air-mass over eastern India is at any time to be moved away to make room for the tropical near the surface, it can only be done by an increased flow of north-westerly air, usually through the agency of a deformation field over Arabia. It may be

[1] Such occurrences often give a clue to the future lie of the stress axis of a major deformation field.

FIG. 1

DEPARTURE OF MEAN TEMPERATURE OF DAY
$\frac{1}{2}$(MAX + MIN), FROM FIVE-DAY NORMAL °F
MAY 1931.



mentioned that even during the monsoon the destruction of the 'cushion', *i.e.* a break in the monsoon, is usually associated with the activity of field *C*.

Identification of the air-masses.—The fresh extra-tropical is a distinctly cold and dry current and its advent is usually well indicated by progressive regional falls of both maximum and minimum temperatures. A few hints as to the practical methods employed for distinguishing the tropical and the equatorial currents and determining the trend of their interaction at the surface and aloft are given below:—

(*a*) *Arbitrary criteria.*—

(i) The isopleth of 20 mb. vapour pressure marks out the boundary between pure tropical and equatorial air-masses.

(ii) During May, for instance, maximum temperatures of 105°F or higher for the tropical and 92°F or lower for the equatorial at the surface are appropriate.

(iii) The fresh monsoon air in July has a maximum temperature of about 66°F and a minimum of 63°F at a height of about a kilometre and a half above M.S.L. (Normand's criterion derived from the data of Mahabaleshwar, 4,534 ft. high).

(iv) From 4.5 km. upwards the trend of the trajectories, on entry into the Indian region, usually indicates the air-mass: *e.g.*, north-westerly or north-easterly winds are extra-tropical; westerlies and south-westerlies, tropical, transitional or monsoon according to the time of the year; and south-easterlies, equatorial.

(*b*) *Surface temperature changes.*—A series of charts is drawn showing changes in periods of 24 and 120 hrs. in the maximum, minimum, dry [1] and wet bulb temperatures at the several reporting stations. All changes of the order of ± 2°F in 24 hours in the first three temperatures over the plains of India (i.e. the changes at the peak of the frequency graph of the usual day-to-day fluctuation) are ignored. The changes due to katabatic flow over the sub-montane regions and the land and sea breeze effects in the coastal districts are duly taken into account. The regions, in which both dry and wet bulb or maximum and minimum temperatures are either falling or rising, are then separated out. In the charts showing the dry and the wet bulb changes the corresponding vapour pressure changes are also plotted. It must be admitted that these charts give rise to knotty questions of complicated differential diagnosis, particularly in the presence of weather phenomena and patches of stagnant and mixed air-masses. Nevertheless, it is found that significant and consistent changes in surface temperatures are connected with the activities of fresh air currents aloft.

(*c*) *Surface abnormalities.*—The appearance and travel of appreciable departures of the meteorological elements from five-day normals are often

[1] Small changes in dry bulb temperature in shorter periods are not easy to interpret as the diurnal range is high in India.

found to be helpful in determining the trend of movement of the equatorial and the tropical up to moderate heights. For example, when, in the absence of weather phenomena, a significant patch of negative maximum temperature departures over northern India begins to move from south-east to north-west the inference would be that the tropical air is being replaced by the equatorial.

(*d*) *Surface horizontal gradients.*—The packing of isopleths of the several elements, particularly those of the wet bulb temperature and of vapour pressure, often indicate a separation of the equatorial from the tropical. Again, except over extra-tropical India in winter and the submontane regions in other seasons, fresh cold air is first observed at high levels and fresh tropical and equatorial at the surface. Of the tropical and the equatorial, the former is observed at the upper levels first. The isobars are therefore nearly always a good guide for the drawing of trajectories of these two currents.

The problem of forecasting.—The bulk of the winter precipitation occurs in association with western disturbances, which usually originate in extra-Indian fields of action and may, for the present, be left out. In this paper attention will accordingly be confined to the forecasting problem outside the winter season.

If it is assumed that fresh cold air is never to be found in the lower layers except over extra-tropical India in winter, the forecasting problem, in the light of the surface data, is reduced to a determination of the interactions of only two air-masses, *viz.*, the tropical and the equatorial. As explained already, however, (*vide* p. 77), the line of discontinuity between these two dominant currents at lower levels would soon attain a steady state and precipitation, unless traced to activities higher up, would be expected to be very much restricted, mainly to hilly regions. During the monsoon even the fullest consideration of the saturated adiabatic lapse rate, with all the relevant trigger actions, such as auto-convergence [1], intermittent sunshine, orography, etc., would at best lead us to discern rainfall of a fitful nature and in the other seasons no positive clue could at all be obtained of the vast thunderstorm activity experienced over the country. In other words, no forecast, even of moderate to heavy rainfall or other pronounced phenomena, could be made by the application of rigid reason to all relevant facts. If, in order to overcome this handicap, particular forms of instability were to be examined, then daily aeroplane ascents at a number of stations to provide the upper air data necessary for the purpose, would be indispensable. Notwithstanding the absence of such arrangements, however, one cannot fail to perceive, in the precipitation charts of different periods, marked indications of 'cold front' effects in the upper levels, over one region or another, according to season. Nevertheless, no means being available of anticipating or even identifying the fronts straightaway, indirect methods of analysis of charts must be resorted to.

[1] A vast field of monsoon air often develops a line of cleavage under stress of growing deformation fields and rain occurs at discontinuities of velocity.

Convergence patterns.—The various layers of the atmosphere are normally characterised by seasonal convergence patterns of large dimensions. These patterns aloft are rather simple, consisting of deformation fields and other similar designs which are most useful to the forecaster. An important one of these is the whirl, which may be regarded as a special case of the deformation field [1]. The daily weather charts show that symmetrical major deformation fields between a dry current and a moist current form at moderate heights above ground and minor ones at low levels.

It is well known that during each season weather phenomena over the plains of India have a marked tendency towards a particular configuration. Consequently, the most useful method of short period forecasting would be one which brings out this configuration from the seasonal discontinuities at various levels. Our present practice, accordingly, consists primarily in the drawing of detailed convergence patterns at the several levels aloft, between air currents having obviously different trajectories. Although pilot balloon data, telegraphed every day to the forecasting centres, are restricted to 6 km. above M.S.L., the correspondence [2] of the axes of deformation fields at different heights in a thick enough layer of the atmosphere often gives important clues to the coming weather 24–120 hrs. ahead.

The convergence patterns generally noticed besides the deformation fields are—

(i) a southerly or south-westerly current striking the Himalayas and allied ranges and then diverging.

(ii) a south-westerly current striking a dominant north-westerly extra-tropical or tropical current and then deflecting south-eastwards. This pattern is often noticed over north-west India.

(iii) a dominant south-westerly current striking a dominant south-easterly and giving rise to a southerly current often producing thunderstorms, *e.g.*, in the summer months in the Bombay Deccan and during the monsoon over the Punjab.

---

[1] While explaining popularly Field *B* (*vide Science and Culture*, March 1938, p. 459) to a newspaper reporter in response to enquiries regarding a trying summer in 1931, Sen used somewhat different nomenclature as would be seen from the following extract which appeared in the 'Englishman' (Calcutta) on the 8th June, 1931:—

'The monsoon is at present engaged in making Burma a very wet country and its further progress is being retarded by an inconsiderate fork of cold wind from the Himalayas between the prongs of which it is caught. There are indications, however, that the fork will soon close and there will be a fresh outbreak in Burma or, in meterological terms, a depression and after that our monsoon will hasten on its way to Bengal.'

[2] The projections on the ground of axes of extension of corresponding deformation fields aloft and on the surface may be within 100 miles of each other. The estimate is based on measurements on small scale charts. The axes at very high levels appear to be shifted to the equatorial air side in the summer months.

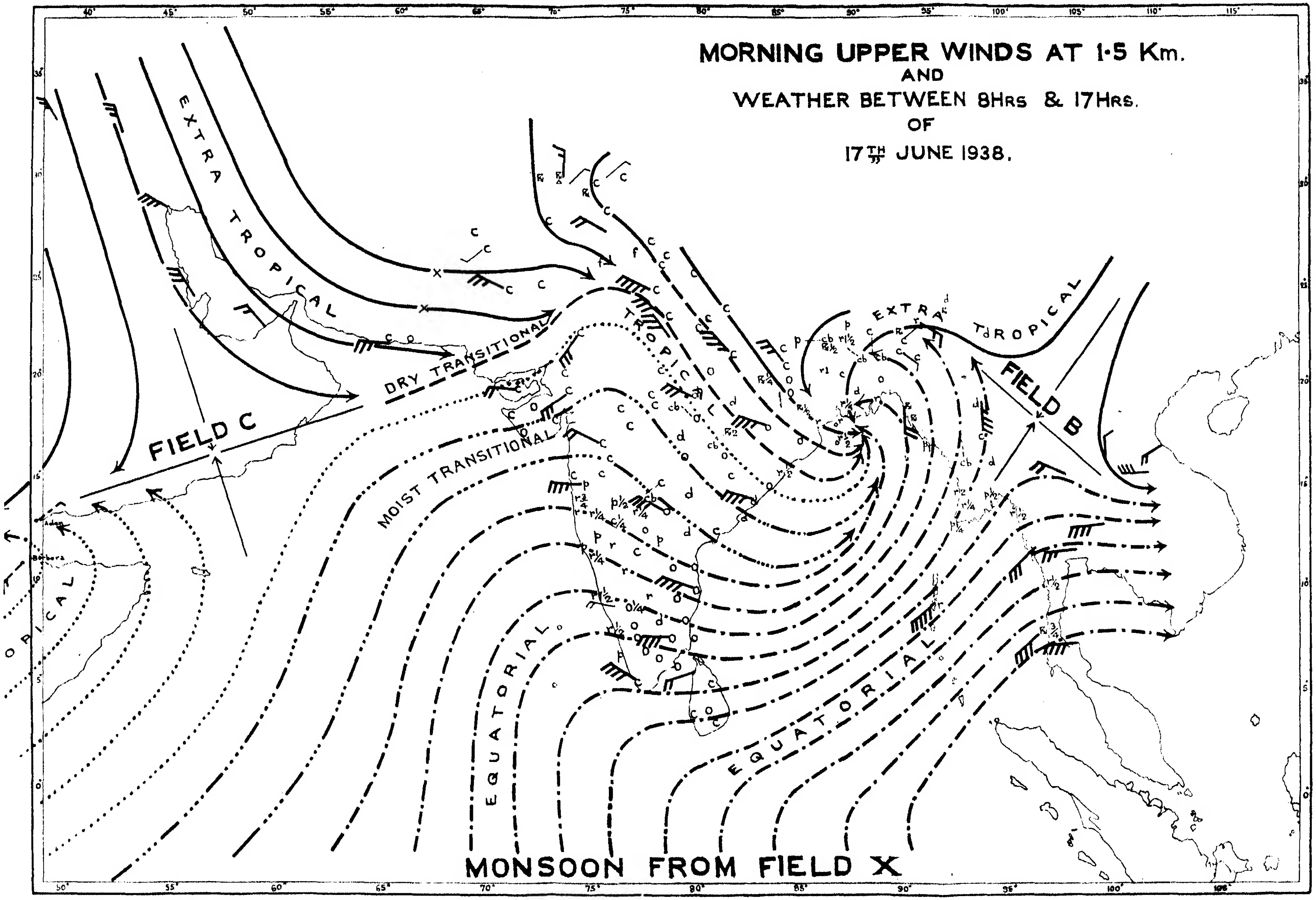
(iv) a northerly extra-tropical or tropical striking a dominant south-westerly current and becoming south-westerly. This pattern is often noticed over the coastal areas.

The main underlying idea in the interpretation of convergence patterns is that two different air currents, while flowing side by side some distance in the same direction, develop under stress a band or axis between them, characterised by marked vorticity [1]. If this pattern has sufficient thickness, conditions become favourable for weather phenomena along the axis. The character and intensity of the phenomena naturally depend on whether the vorticity is between the tropical and the extra-tropical, the equatorial and the extra-tropical or the equatorial and the tropical. As a rule, the first case results in duststorms or dry thunderstorms, the second in severe thunderstorms with abundant rainfall and the third in thunderstorms of a minor type with light rain. It is thus obvious that the seasonal dispositions of these axes at the various levels and their migrations from normal positions would greatly bear upon the type and distribution of weather to be expected. The study of the situation would be further facilitated if it is remembered, as observation shows, that the momentum of the flow of cold air in a general deformation field above the differential level shapes and guides to an appreciable extent the convergence patterns in the fields below.

Mechanism of weather over India.—General deformation fields.—The main seasonal phases of the wind structure and weather over India are easily explained by the linear and angular oscillations of four general deformation fields, *viz.*, field *A* over India (in the non-monsoon months), field *B* over China-Burma region (in the monsoon months), field *C* over the Arabian region and field *X* in the southern hemisphere (see Figs. 2 and 3). With due regard to the interactions of these fields, it can be more or less clearly pictured how their positions and vertical extent will determine the distribution and character of weather in the Indian region, at any given time. It is observed that in winter, field *A* is dominant over the country and in the monsoon field *B*, while during the transition months, both *A* and *B* participate, the external influences in all the seasons being exercised by fields *C* and *X*. It is particularly interesting to study the parts played by the different fields during important changes of season. In connection with the onset of the monsoon, for instance, the characteristic events are that field *A* gradually vanishes, that field *C* apparently moves southwards and sometimes has its axis of extension running from SW to NE over the Arabian Sea and that field *B* is more or less over Burma. At the same time, an intermittent swaying of the axis of extension of field *X*, apparently associated with mid-winter conditions over the southern hemisphere, leads to a periodical delivery of huge masses of cold and moist air at the equator.

[1] It is interesting to note that the orography of Cherrapunji is on the lines of a horse shoe with extensions on both sides, giving the impression of the axis of extension of a deformation field.

FIG. 2



NOTES :—1. Symbols used are the same as those in figure 3.
2. Winds at hill stations about 1·5 km. high are shown by thin arrows.
3. Direction of motion of Cb cloud is shown by dotted line ending at station circle.
4. In the afternoon Tropical and moist transitional currents penetrated into the extreme north of the country where widespread thunderstorms occurred by following morning.
5. The winds over Vinh (Lat. 18°40′ N, Long. 105°40′ E) and Vientiane (Lat. 17°58′ N, Long. 102°36′ E) refer to 1·0 km. and 1·3 km. respectively.
6. The wind over Aden (Lat. 12°49′ N, Long. 45°02′ E) is the normal resultant wind at 2·0 km.
7. The wind over Berbera (Lat. 10°22′ N Long. 45°02′ E) is the prevailing wind at 1·0 km.

If the preparations for the monsoon start early, *i.e.* if, for instance, field *A* is definitely destroyed by May and field *C* shows a premature and frequent dominance with its axis of extension over the Arabian Sea, the advent of the monsoon may also be expected, as a rule, to be early.

Methods in practice.—As already pointed out, important development of weather in India is to be expected mainly along the axis of extension of a deformation field (between any two of the three principal air currents), in and around whirls, and over regions of auto-convergence and velocity-discontinuity in the equatorial current, especially during the monsoon. In drawing these patterns the only method available at present, to verify the identity of the different air-masses, is to correlate, as far as possible, the regional changes in upper winds with those in the surface elements below. As is well known, however, a correct interpretation of the latter is notoriously difficult. For example, a fall in the maximum temperature may be due to suitable spells of cloudiness, katabatic flow of cold winds, arrival of fresh extra-tropical air, rain through tropical air, thunder or duststorms, transport of fresh equatorial air into regions originally under the tropical, or mixing of different air-masses at the surface. There are similar difficulties in respect of the variations in other elements. Efforts are, however, made to get at the real sequence by working out and examining, besides the changes in 24 hours, which often represent only local fluctuations in the field, 120 hours' changes, which generally indicate the regional trend. It is by this and similar means and through a process of gradual elimination in the light of the life-history of each air-mass that a reasonable correlaton of the changes in the surface elements with those in the upper winds can be rendered feasible and necessary inferences drawn.

Among the factors helpful in the analysis of charts, a marked divergence of trajectories in an air-mass is of particular utility in determining the position of the stress axis. A sudden increase in wind speed, in the same horizontal plane, often indicates the presence of discontinuity, while significant patches of 'present and past weather', with proper reference to the upper wind distribution at each level, are of great use in defining the prevailing patterns. It may be noted here that the axis of a major deformation field within the Indian region has been found to have a marked tendency to run more or less parallel [1] to the coast. Even the auto-convergence lines show this preference during the monsoon. In actually drawing the convergence patterns the charts are taken up first from low levels upwards, *i.e.* from 0·5 km. level to 2 km. or so, referring to the isobaric chart as a rough guide and then from high levels downwards, *viz.*, from 6 km. to 3 km. taking the wind directions at source regions as the criteria for distinction. The finished patterns are then viewed, so to say, from above, as if the whole series was arranged on a 'cake stand'. In making out the patterns between 2–4 km., a knowledge of the heights of the differential

[1] The lie of the stress axis of a major deformation field within India is either from SE to NW or from SW to NE, which, it appears, are the stable positions.

levels over various regions is necessary, so that the 'cold fronts' may be located but, in the absence of upper air data, it is not always possible to gain this knowledge. Nevertheless, the data in Table II, the extent of subsidence of the tropical and the extra-tropical [1] (seen from the mode of descent of convergence patterns), the character and intensity of weather along the axis of extension and the particulars of failure of forecast may furnish a working hypothesis.

In Fig. 3, a concrete example is given of the method followed in the drawing of convergence patterns.

The important auxiliary charts given in Fig. 4 are self-explanatory.

The first important point to notice is that a cold wave started at the frontier in the rear of a western disturbance on the 23rd April, 1934. Temperature fell over Baluchistan and the 'zero line' in Fig. 4 (*c*) appeared over the frontier. This cold wave was later augmented by others in the wake of fresh western disturbances. Moreover, discontinuities in the lower levels caused rain over the western Himalayas between the 23rd and 25th April and the consequent cooling further reinforced the cold wave. The consecutive positions of defects of 'mean temperature of day' from the normal by about 8°F are shown on the chart. The bifurcation of the cold wave at the surface in its south-eastward travel was apparent from the consecutive positions of the 4°F line (not reproduced) and approximately indicated the probable lie of the stress axis. The 'zero line' ran from Assam to Malabar by the 30th April. A major deformation field which is shown in Fig. 3 appeared at 3 km. Its base was about 1·5 km. above mean sea level and the top reached higher than 6 km. The associated occurrence of fog along the Mekran and Kathiawar coasts is significant.

The configuration of isotherms in Fig. 4 is almost a 'shadow' on the ground of the general deformation field aloft. Fig. 4 (*d*), representing the changes in wet bulb temperature in 120 hours, shows how the invariant character of this element helped in demonstrating that the source at the north-west frontier was connected with the seats of action in Assam and the Peninsula. In cases like this the growth and ultimately the dominance of dry air to the north of the axis of extension, in spite of the minor fluctuations occurring throughout the field, is the most remarkable feature and often serves as the chief basis of analysis.

The comparative constancy of wet bulb temperature is of particular help, when, owing to circumstantial peculiarities, the general response of the surface elements to the regional changes in wind directions above is either blurred or wholly masked. Such instances are happily not many and are mainly

---

[1] In this connection it is to be remembered that, while flowing over the equatorial, the tropical goes head forward, *i.e.* the upper layers are in advance of the lower layers. In the case of the extra-tropical however conditions are reversed. This is incidentally one way of distinguishing the tropical from the extra-tropical simply with the aid of the trajectories.

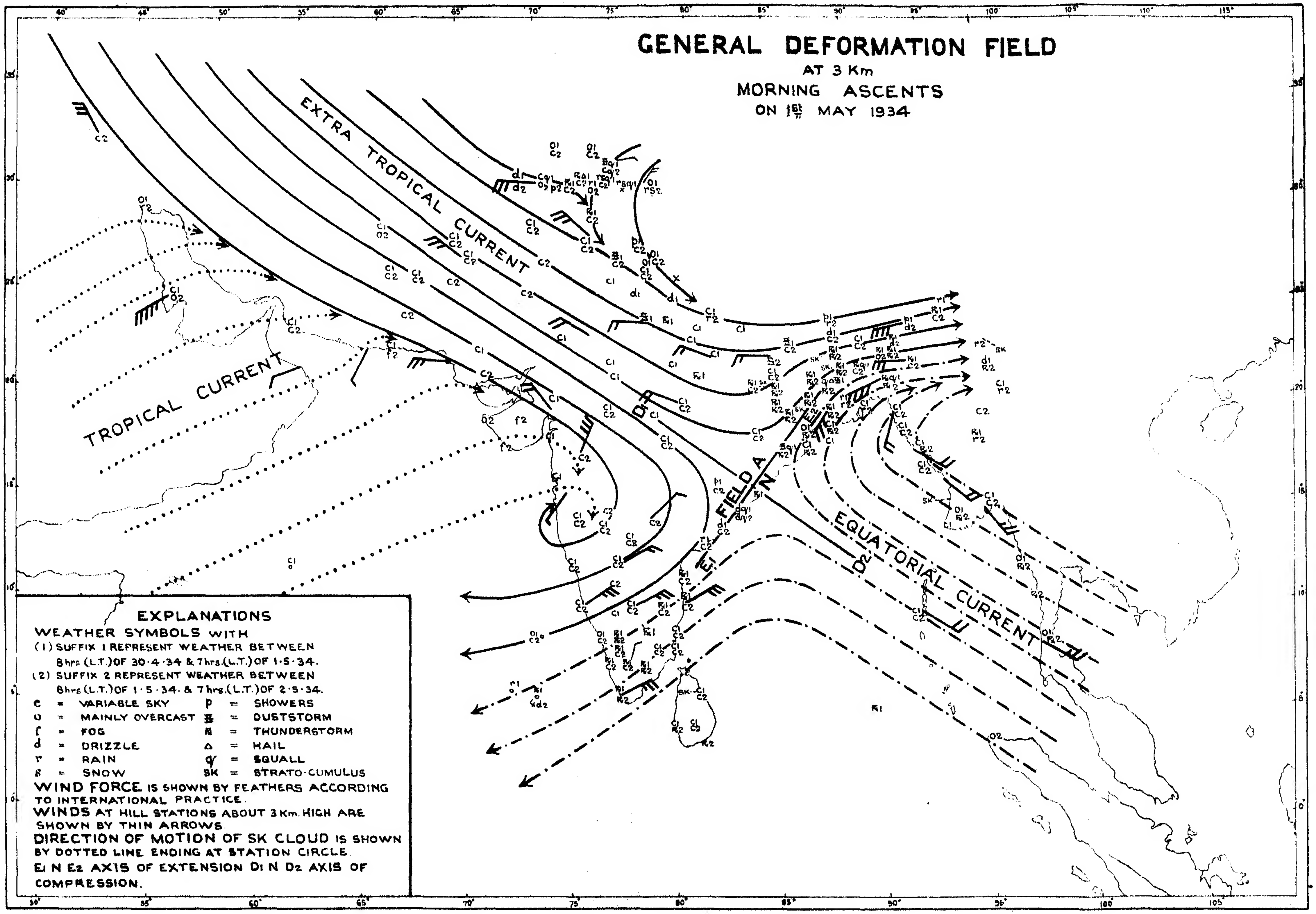
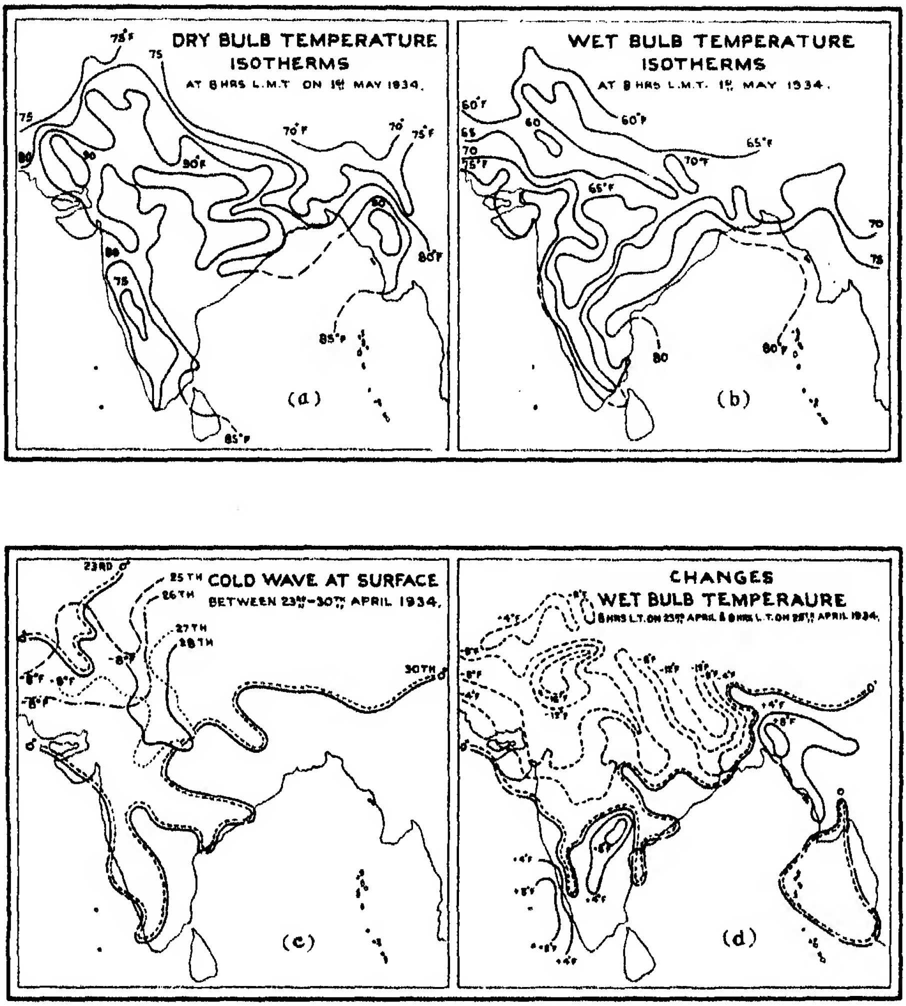

GENERAL DEFORMATION FIELD
AT 3 Km
MORNING ASCENTS
ON 1st MAY 1934
EXTRA TROPICAL CURRENT
TROPICAL CURRENT
EQUATORIAL CURRENT
FIELD A
EXPLANATIONS
WEATHER SYMBOLS WITH
(1) SUFFIX 1 REPRESENT WEATHER BETWEEN 8hrs (L.T.) OF 30·4·34 & 7hrs. (L.T.) OF 1·5·34.
(2) SUFFIX 2 REPRESENT WEATHER BETWEEN 8hrs (L.T.) OF 1·5·34. & 7hrs. (L.T.) OF 2·5·34.
c = VARIABLE SKY
o = MAINLY OVERCAST
f = FOG
d = DRIZZLE
r = RAIN
s = SNOW
p = SHOWERS
DUSTSTORM
THUNDERSTORM
HAIL
SQUALL
SK = STRATO-CUMULUS
WIND FORCE IS SHOWN BY FEATHERS ACCORDING TO INTERNATIONAL PRACTICE.
WINDS AT HILL STATIONS ABOUT 3 Km. HIGH ARE SHOWN BY THIN ARROWS.
DIRECTION OF MOTION OF SK CLOUD IS SHOWN BY DOTTED LINE ENDING AT STATION CIRCLE.
E1 N E2 AXIS OF EXTENSION D1 N D2 AXIS OF COMPRESSION.

FIG. 3

FIG. 4



NOTES FOR (c) TRAVEL OF ISOPLETHS OF NEGATIVE DEPARTURES OF MEAN TEMPERATURE OF DAY, ½(MAX + MIN), 2°F BELOW NORMAL BETWEEN 23RD AND 30TH APRIL 1934.

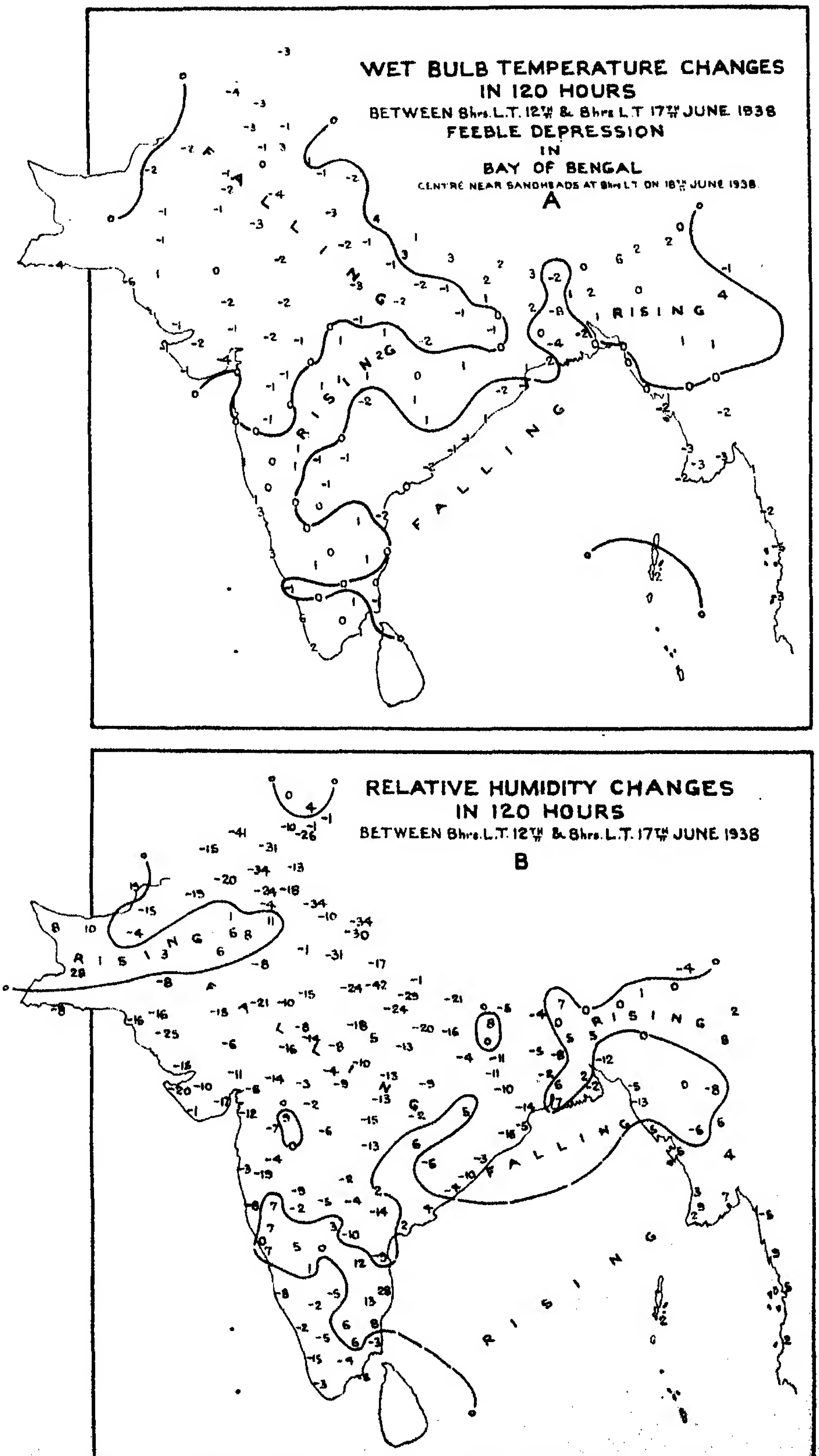
TO THE NORTH OF THE ZERO LINE TEMPERATURES WERE BELOW NORMAL AND TO THE SOUTH ABOVE NORMAL ON THE DATES SHOWN AGAINST EACH LINE.

THE NORMALS OF TEMPERATURES USED FOR COMPARISON ON ANY DAY REFER TO THE STANDARD 5-DAY PERIODS IN WHICH THE PARTICULAR DAY LIES, IN THE PRESENT CASE NORMALS FOR THE PERIODS 20TH TO 25TH AND 26TH TO 30TH APRIL HAVE BEEN USED.

associated with the formation of feeble depressions, particularly during the monsoon or after a succession of storms. The following case is illustrative.

On 18th June, 1938, a feeble depression formed in the Bay of Bengal off the Orissa coast. The regional changes in the wet bulb temperature and relative humidity are depicted in Fig. 5.

FIG. 5


WET BULB TEMPERATURE CHANGES
IN 120 HOURS
BETWEEN 8hrs.L.T. 12TH & 8hrs L.T 17TH JUNE 1938
FEEBLE DEPRESSION
IN
BAY OF BENGAL
CENTRE NEAR SANDHEADS AT 8hrs L.T ON 18TH JUNE 1938.
A
FALLING
RISING
RISING
FALLING
RELATIVE HUMIDITY CHANGES
IN 120 HOURS
BETWEEN 8hrs.L.T. 12TH & 8hrs.L.T. 17TH JUNE 1938
B
RISING
FALLING
RISING
FALLING
RISING

It is seen from Fig. 5A that the wet bulb temperature changes in 120 hours were slight. The tongue in northern India, over which wind shifts aloft were most marked, was nevertheless significant inasmuch as it could be regarded as part of one system, neglecting the falls over the coastal areas, which were obviously due to other causes. It is also noteworthy that relative humidity fell over northern India (Fig. 5B) in spite of rain.

From what has been said in the preceding paragraphs it will be clear that even in the absence of upper air temperature data, the method of drawing convergence patterns is more or less rigidly defined, leaving little room for personal predilections. The latitude that there may be is still further restricted by the daily verification of forecasts and the consequent redrawing of the old fields.

The establishment or dissipation of a major deformation field, as known from experience, usually takes about five days. As all weather phenomena are essentially associated with the activity of convergence patterns, it is evident that, with the mode of analysis recommended, general forecasts or 'outlooks' 5 days ahead can be considered to be a practical proposition. The scope of such forecasts is all the more widened in the case of depressions and cyclonic storms the formation of which, as the present method of analysis shows, results from the convergence of three air-masses, that is the interactions of two deformation fields [1] with their axes of extension suitably inclined to one another. Thus, for instance, during the usual break in the monsoon preceding the formation of a depression in the Bay of Bengal, the typical warm spell over northern India arising out of the importation of the tropical by field C, as also the active monsoon which prevails in Bengal during the reinforcement of field B, is likely to last about five days and can usually be foreseen. Similarly, after the depression has formed, a spell of bad weather for 5 days can be indicated over certain regions.

Summary of important points.—For forecasting purposes, leaving out periods of cyclonic storms in the Indian Seas, the following points should be noted:—

(*a*) In winter the Indian region is dominated by field A, field C also becoming active when a western disturbance is approaching Baluchistan. Field B meanwhile displays occasional activity over Lower Burma. The lie of the axes of extension of these fields enables one to forecast weather 24 to 48 hours ahead, the period of forecast for any region usually depending on the thickness and persistence of the field concerned. The activity of the north-east monsoon is closely associated with the axis of extension of field A, when over the south-west Bay of Bengal, and a revival may be foreshadowed, sometimes, about 5 days ahead.

[1] In June 1938, for instance, no depression formed in the Bay of Bengal until field C extended an arm to the field B. It may be noted here that when the third air-mass arrives there may even be a rise of pressure initially.

(*b*) In the summer months the governing fields are *A*, *B* and *C*, the first of which gradually loses control with the rise of the differential level. Taking advantage of the probable lie of the axes of extension of the general deformation fields,

(i) forecasts of rain over the western Himalayas, the south of the Peninsula and Assam may sometimes be issued about 5 days ahead;

(ii) widespread nor'westers in Bengal, considering particularly the activities of fields *A* and *B* may be forecasted some 8 to 48 hours in advance.

(*c*) During the monsoon period, the simultaneous activity of fields *C* and *B* gives widespread rainfall over the country, as the resulting whirl is generally over the central parts. The activity of field *C* alone, with the axis of extension running over Arabia and Iran, gives rise to a 'break' in the monsoon, owing to the transport, under stress, of large masses of tropical air into northern India. It is an occasion, when, with the withdrawal of moist air, subsidence of tropical air takes place on a large scale. A favourable lie [1] of the axis of extension of field *C*, however, may cause heavy rainfall along and near the west coast. Field *B*, by itself, affects mainly Tenasserim, east and north Bengal and Assam, the intensity of weather over which regions is well known. An important problem in this season is to indicate the duration of wet spells and of breaks. For these, forecasts may usually be issued 48 hours in advance.

It may be mentioned here that orography in general (excluding the extraordinary features, such as the Himalayan ranges, the Cherrapunji region and the like), while it does play some part, presumbly in the adjustment of the axes in lower layers, cannot be held responsible for any main feature of precipitation, because its behaviour is appreciably inconsistent in apparently similar circumstances.

(*d*) In the retreating monsoon period field *A* is gradually re-established and field *X* retreats further away from the Indian area. Weather may be predicted about 48 hours in advance, as a rule.

In winter and summer small whirls often travel across northern India from west to east. At the height of the monsoon, the tropical air may not often reach the sea areas and whirls may form inland and travel from east to west. In the retreating monsoon period there is often a family of whirls affecting the weather over the country. All these may be associated with minor and subsidiary deformation fields. Weather associated with minor and subsidiary fields may be predicted only 8–24 hours ahead.

As regards conditions associated with cyclonic storms, the following points are noteworthy:—

According to the present method of analysis Indian cyclones arise out of the interaction of two deformation fields (three air-masses) a study of which

---

[1] Cf. the early monsoon on the west coast this year and the associated heavy rainfall in Gujarat on the 13th June.

should make it possible to predict the appearance of unsettled conditions about 48 hours in advance. When the cyclone is formed, the forecast of its intensity and direction of motion should similarly be possible some 48 hours in advance. Taking advantage of the statistics collected so far, the rainfall patterns and the typical regional spells of bad weather, associated with cyclones in different seasons, may be predicted in a general way about 5 days in advance.

The various points touched upon in this paper are under further study and are expected to be discussed in detail later.

Discussion.

President: I would like to ask whether the line of extension is a front ?

Mr. S. Basu: What do the 120-hours' changes represent ? Are they the differences between the first and the fifth days' values or do they take into account the trends of variation in the intermediate days ?

Mr. V. V. Sohoni: How are the air-masses over the United Provinces and north-west India, which are designated as 'extra-tropical air', identified?

Mr. K. P. Ramakrishnan: It is stated in the paper that one of the methods by which cold air can reach the surface is subsidence. Was the air originally so cold that, even after the heating due to subsidence, it could still remain colder than the rest ?

Mr. A. K. Roy: The distinction between thunder-rain and thunderstorm with light rain is not quite clear. Does it mean that rain in the first case is of thunderstorm type but is not actually associated with thunderstorm ? If so, it is not clear why an interaction between the equatorial and the extra-tropical should be less favourable for thunderstorm than that between the equatorial and the tropical.

Dr. S. N. Sen: The line of extension is a front. 120 hours' changes are the differences between the first and the fifth days' values. The extra-tropical air over north-west India and the United Provinces is, in the absence of upper air temperature data, identified by watching the regional changes of dry bulb and wet bulb temperatures at the surface, together with the upper winds. At the beginning of a spell of subsidence temperature at the surface may not fall, it may even rise; but, with the progress of subsidence, due to fresh supplies of cold air, there is, eventually, an appreciable fall of temperature at the surface. Convergence between the equatorial and the extra-tropical results, as a rule, in more intense thunderstorms than that between the equatorial and the tropical. This point will be suitably explained in the published paper.

FORECASTING OF NOR'WESTERS IN BENGAL.

By S. K. Pramanik, *Meteorological Office, Alipore, Calcutta.*

(*Read at Symposium, July 25-26, 1938.*)

1. The Nor'westers or Kalbaisakhis (calamities of the month of Baisakh) are severe thunderstorms which occur in Bengal during the summer months March to May, some of which reach tornadic violence and cause considerable damage to property and sometimes even loss of life. The wind in these thunderstorms comes generally from some north-westerly direction and hence they are called 'Nor'westers'. In some cases, funnel-shaped clouds characteristic of tornadoes have been noticed.

2. In order to be able to forecast the occurrence of Nor'westers, it is necessary to have an idea of the mechanism of these phenomena and of the conditions necessary for their occurrence.

3. This problem has been engaging the attention of Indian meteorologists from a long time and Blanford,[1] Eliot,[2] Normand,[3] Roy and Chatterjee,[4] Sohoni,[5] Sen,[6] Das,[7] Desai and Mal,[8] and Sur and Chatterjee [9] have considered the question from different points of view. It is generally agreed that the Nor'westers are not 'local heat' thunderstorms. This appears to have been recognized by Eliot as early as 1876. They also do not occur when the whole of north-east India is overrun by one air-mass, i.e., during winter when west to north-west winds prevail and during periods of strong monsoon when moist winds from the Bay prevail. They occur mostly during the transition period from the winter season to the rainy season, i.e., when two different air-masses, west to north-west winds of land origin and moist winds from the Bay, co-exist over Bengal.

4. Different explanations of the generation of the Nor'westers have been given by various authors. Roy and Chatterjee advanced the view that Nor'westers originate through the overrunning of a warm moist southerly or south-westerly current by a westerly or north-westerly cold air with a high lapse rate. They arrived at this view by a study of some meteorograph records obtained at Jhikargacha earlier in the same year. They found that the conditions under which Nor'westers occurred in Bengal were similar to those giving rise to tornadoes in the Mississippi valley of the United States of America. They further suggested that the marked rise in the absolute humidity of the southerly wind in the afternoon, which they found from the ascents, was the cause of the more frequent occurrence of Nor'westers during afternoon than during other times of the day. Sen suggested that Nor'westers are due to the katabatic flow of cold air wedges from the eastern Himalayas advancing along the valleys and undercutting moist southerly winds over the

plains of Bengal. Sohoni described the weather types associated with Nor'-westers. He found that Nor'westers occurred mainly when there was a passage of a depression or low pressure wave towards north-east India from the west and when there was a strong west to east pressure gradient over Bengal. Both these conditions, it might be mentioned, would be favourable for the flow of southerly moist winds into Bengal from the Bay. He concluded that, in the majority of cases, Nor'westers are caused by the overrunning of moist warm air by a cold air with high lapse rate, which view had already been advanced by Roy and Chatterjee. He thought that the occurrence of Nor'-westers near and after sunset, some hours after the maximum insolation effect, might be due to radiation. Das suggested a close analogy between the mechanism of Nor'westers and that of cold fronts. He supposed that the cold air was heaped like a mountain near the foot of the Himalayas which breaks into two parts, one moving initially towards the east and the other towards the west. Its further movement would then be influenced by friction, the orography of the country including the slope of the ground, the temperature contrast, the deflective force due to the rotation of the earth and the prevailing wind. He thought that the cold air advanced in the form of a 'squall head' and calculated the velocity to be expected on certain assumptions. This year, Desai and Mal have studied the mechanism of afternoon Nor'westers. They agree that the condition just at the moment of starting of the Nor'westers is the same as that visualized by Roy and Chatterjee. They do not, however, agree with Roy and Chatterjee that the upper air is generally potentially colder than the lower air, and think that the superadiabatic lapse rate is neither the characteristic of the upper air nor does this high lapse rate occur except at the time of starting of the Nor'wester. They start with certain assumptions of lapse rate and distribution of temperature in air, and work out the effect of insolation. They find an inversion in the morning near the separation layer which would prevent occurrence of thunderstorms as long as this is present. They also find that if the insolation is sufficient the convection currents would move up and ultimately wipe off the inversion. At this stage great instability would result at the separation layer, which would cause the cumulus clouds and the moist air current to shoot up with explosive violence causing a rapid descent of the upper air thereby generating a Nor'wester. Recently Chatterjee and Sur have described the results of the ascents of Clown Balloon and Dines' meteorographs at Jhikargacha in April and May 1929. They found that in this season during the morning there was an inversion between 0·5 and 1·5 km. (which Desai and Mal concluded should exist on the premises they started with) with latent instability in the atmosphere above. This inversion may persist in the afternoon but is often wiped off. They found that the existence of latent instability was necessary for the occurrence of thunderstorms but the converse did not hold. They also found that the cooling in the majority of the cases could be attributed to the descent of cold air from above, though in some cases they found that the air could only

have come from some neighbouring region of thunderstorm. They also thought that this cold air of a neighbouring thunderstorm could initiate a thunderstorm.

5. The mechanism suggested by Roy and Chatterjee and Sohoni appears to require that the Nor'westers should occur at all hours of the day instead of the majority of them occurring during the afternoon only, since the two air-masses are present over Bengal throughout the day. Objection to Sen's theory of undercutting by cold easterly Himalayan air flowing down the valleys is that Nor'westers often occur when there is practically no easterly or northerly current flowing down the valleys and that there is also no time sequence in the occurrence of the Nor'westers. It may, however, be mentioned that on some occasions some of the Nor'westers can apparently be attributed to this cold Himalayan air. Objection to Das's theory that the phenomenon is similar to that of cold wave of temperate latitudes is the absence of their occurrence along a front and the absence of time sequence in their occurrence which one should expect from this. It may, however, be pointed out that we get north-easterly winds in lower levels at Gaya in the morning on some days when Nor'westers occur. Desai and Mal agree with Roy and Chatterjee as to the mechanism at the moment the Nor'wester starts. They have explained how this great instability is reached at that moment due to the effect of insolation and did not exist before. They have also accounted for the temperature changes on the ground on this basis. One will, however, have to see how far their theory can explain the actual data of upper air collected by meteorographs. It is also doubtful if the late occurrence of Nor'westers can be attributed solely or mainly to radiation as suggested by Sohoni and Desai and Mal.

6. It appears that while some of the Nor'westers may be due to the action of cold fronts or undercutting by cold easterly Himalayan air the majority of those which occur in the afternoon depend on some insolation effect. In the morning there is an inversion between 0·5 and 1·5 km. with moist air below and dry air above, generally with latent instability. The effect of insolation is like heating unequally a slightly inclined layer of liquid from below with the result that convection currents rise irregularly over the country. With the advance of day and greater heating, these currents go higher and higher, and if the heating is sufficiently great they reach the inversion layer which is wiped off causing marked instability at the boundary layer. Convection currents, when they reach this layer, shoot up with explosive violence causing a rapid down flow of the upper air thereby generating a Nor'wester.

7. It would seem, as a consequence of what has been stated above in § 6, that the occurrence as well as the intensity of afternoon Nor'westers would depend upon the height of the inversion layer and the amount of insolation. If the inversion layer is low, when it is wiped off by the convection currents, the instability at the boundary will not be large and as such there will be cumulus and cumulo-nimbus clouds which may even be accompanied by a mild or a moderate thunderstorm. When the inversion layer is high and when

the convection currents reach this layer, the instability produced will be great and there will be a violent thunderstorm or Nor'wester. It may be mentioned that the chances of the convection currents reaching the inversion layer will be greater when this is low than when it is high; hence occasions of occurrence of cumulus and cumulo-nimbus clouds, which may or may not be accompanied by mild or moderate thunderstorms, will be more numerous than Nor'westers. If this mechanism is correct, we may also have a sort of basis of forecasting of Nor'westers if we could find out the height of inversion layer in the morning and also form an estimate of the maximum temperature likely to be attained in the afternoon. For in this case we may be able to form an estimate of the height to which convection currents will rise and whether they will reach the inversion layer or not. If the inversion layer is not reached there will only be some cumulus clouds, but if this layer is reached then there will be mild thunderstorm or a Nor'wester according as the height of this layer is low or high.

8. There is often a lag of some hours between the time of maximum insolation and the time of occurrence of thunderstorm in the majority of the cases. Some lag can be due to the fact that time is required for the effect of maximum insolation to reach the inversion layer. The lag of some 4 or 5 hours or more cannot, however, be probably due to this cause or, except in some cases, to radiation. Chatterjee and Sur found evidence that the flow of cold air from a neighbouring thunderstorm could start another. There may be a state of affairs when the inversion layer is high and the insolation is not sufficient to raise the convection currents up to this height and wipe off the inversion, but is sufficient to leave warm moist air up to a little distance below this height. The cold air from a neighbouring region where a thunderstorm has occurred earlier flows out and undercuts the air at the place and raises it so that it reaches the boundary layer, causing sudden great instability and generating a Nor'wester. As the height of the inversion layer in a case like this will generally be high, there should be a tendency for the Nor'westers in this case to be severe.

9. Sur and Chatterjee found that in all cases when thunderstorms occurred there was latent instability, but about two-thirds of these ascents relate to a short period before or near the time of the thunderstorm; so it is possible that some morning ascents may not show latent instability but with the advance of day moist air may come in and give rise to latent instability and thunderstorm in the afternoon. It may also happen that, as was actually noticed by Sur and Chatterjee in one case, there might be latent instability in the morning but no latent instability in the afternoon. Cases like this are, however, likely to be few. Sur and Chatterjee also found in a few cases that there was latent instability even in the afternoon but no thunderstorm took place. In these cases it may be that the convection currents could not rise high enough to reach the boundary layer. Nāmias[10] found that similar cases occurred in America. He applied the method of isentropic analysis of

the flow patterns in the free atmosphere, as he believes that a fairly complete picture of the mechanism can be obtained by this, and he found that it held out the hope that all such thunderstorms, if not all summer precipitation, could be forecast with a much greater degree of accuracy. A network of aerological stations taking daily readings of temperature and humidity would be necessary for purposes of isentropic analysis and as such this method cannot at present be applied to the problem of Nor'westers in Bengal.

10. The conditions which appear to be necessary for afternoon Nor'westers are given below:—

(i) Supply of moist southerly air from the Bay of Bengal. It should be fairly thick, say from 1·5 to 2·5 km., but should not be too thick; otherwise the resultant effect might be the same as if there was only the moist air-mass present when no Nor'wester occurred. The surface conditions favourable for this flow of moist air are a low and west to east pressure gradient over Chota Nagpur or neighbourhood. It sometimes happens, however, though not often, that the circulation at higher levels is considerably different from what one would expect from the surface conditions. In this case it is the circulation in the upper air and not the surface condition which is the determining factor.

(ii) There should be a westerly or north-westerly dry air with a fairly high lapse rate flowing over the moist southerly air.

(iii) There should be latent instability.

(iv) Cold easterly Himalayan air down the valleys of north-east Bengal and north-easterly winds at lower levels from north Bengal are favourable but do not appear to be essential.

If the above conditions occur, Nor'westers are to be expected. The forecast has, however, to be issued in the morning and for small areas and it is difficult to anticipate the changes likely to occur during the day and to estimate the conditions in the afternoon and as such it does not appear possible at this stage to state definitely what conditions in the morning are sufficient to give rise to Nor'westers in any particular part of Bengal.

REFERENCES.

[1] Indian Meteorologist's Vade-Mecum, Part II, p. 135.
[2] *Ind. Met. Memoirs*, Vol. I, p. 119.
[3] *Ind. Met. Memoirs*, Vol. 23, Part 1, p. 21.
[4] *Nature*, Vol. CXXIV, p. 481, (1929).
[5] *Ind. Met. Dep. Sci. Notes*, Vol. IV, No. 33.
[6] *Nature*, Vol. CXXVII, p. 128, (1931).
[7] *Gerl. Beitr. Geophys.*, Vol. 39, p. 144, (1933).
[8] *Gerl. Beitr. Geophys.*, Vol. 53, pp. 285–304, (1938).
[9] *Ind. Met. Memoirs*, Vol. 26, Part 9.
[10] *Bull. Amer. Met. Soc.*, Vol. 19, January 1938.

Discussion.

Mr. Doraiswamy Iyer: Has Dr. Pramanik made any attempt to forecast weather 48 hours or more ahead with the help of the upper winds and, if so, I would like to know the results obtained. Has the relation between the strength of the upper winds and subsequent weather in north-east India been worked out, in addition to the relation between the direction of the upper winds and subsequent weather.

Mr. P. R. Krishna Rao: The time interval between the occurrence of the Nor'westers and the time of maximum surface temperature may be due to the time taken for the turbulence effect to extend upwards by eddy conduction to the boundary layer between the two air-masses. The actual time interval on any day would depend on the height of the boundary layer and the value of eddy conductivity.

Dr. Roy: Hot weather local storms such as Nor'westers in north-east India (*Kal-Baisakhi*) and duststorms in north-west India (*Andhi*) are, I believe, essentially thunderstorm phenomena. The difference between a Nor'wester and an *Andhi* is obviously due to the difference in the amount of moisture that plays part in the two phenomena. The observations made by Mr. Chatterjee during the Jhikargacha expedition have provided us with the following valuable results:—

1. The free air in Bengal during the months of March to May is characterized by the presence of an inversion in the morning and forenoon at heights varying from 1·5 to 2·5 kms., which weakens or disappears in the afternoon by heat convection.
2. The air-mass below the inversion is a southerly moist current from the Bay of Bengal and that above it is a dry westerly or north-westerly current of land origin.
3. One essential condition for the occurrence of a Nor'wester type of thunderstorm is the accentuation of the southerly moist current.
4. Superadiabatic lapse rates appear in the air-mass near the inversion level during the occurrence of a Nor'wester.
5. Nor'westers are more common in the afternoon and evening.

The western disturbances which travel eastwards through the centre of India as low pressure areas are usually the agents which are responsible for the strengthening of the moist Bay current. A weakening or the disappearance of the inversion is, however, essential before a thunderstorm phenomenon of the Nor'wester type can occur and this is effected by heat convection due to surface insolation. This fact probably explains why Nor'westers are more common in the afternoon and evening than at any other hour of the day.

The appearance of superadiabatic lapse rates in the dry north-westerly land air above the moist air is apparently responsible for the violent character of Nor'wester squalls. It is, however, difficult to imagine that air-mass with superadiabatic lapse rates could persist for any length of time. There is,

therefore, little doubt that the occurrence of superadiabatic lapse rates in a Nor'wester is a temporary phase and yet important in explaining the suddenness of the phenomenon. It is conceivable that the initial heat convection causes precipitation which evaporates in the free air and cools it. Such cooling near the top of the moist air-mass would give rise to temporary superadiabatic lapse rates.

Dr. Normand: The necessary conditions for Nor'westers, as summarized at the end of the paper, are in agreement with the views of most other workers on the subject. Perhaps too much stress has been paid to the inversion layer and to the suggestion (in one of the diagrams shown) that the inversion layer is converted without change of height into a layer of great instability. Once you grant latent instability as the source of energy, it follows that during the release of that energy there must be an apparently unstable layer shown in every record of ascent through, and at the top of, the developing cloud.

Dr. Pramanik: I have not made any attempt to forecast for 48 hours or more with the help of upper winds alone, but I have made a few forecasts based on the surface and upper air charts with a fairly reasonable amount of success. I have not also worked out the statistical relation between the strength and direction of upper winds and the subsequent weather in N.-E. India. I may, however, mention that in issuing forecasts both the direction and force of the upper winds are taken into consideration and that these forecasts are generally borne out by the subsequent weather. The point mentioned by Mr. Krishna Rao is implied in the paper. Dr. Roy's views are in general agreement with those mentioned by me. As regards the point mentioned by Dr. Normand, I may say that there is a change in height of the inversion layer during the course of the day but it appears unlikely that there is much change in height when this layer is converted into one of great instability.

UPPER AIR DATA AND WEATHER FORECASTS.

By K. R. RAMANATHAN, *Colaba Observatory, Bombay.*

(*Read at Symposium, July 25-26, 1938.*)

Introduction.—The last twenty-five years has seen a great change in our mode of looking at weather phenomena. Previously, the attention of meteorologists was mainly directed to the pressure map and the movement of systems of isobars across the map with the associated changes of weather. More emphasis was laid on the effects of weather at different places on the surface of the earth than on the physical phenomena taking place at any moment in the body of the atmosphere. This was not due to any want of appreciation on the part of the meteorologists of the importance of upper air data for a better understanding of atmospheric processes; the reason was mainly the non-availability of data. The growth of aviation has assisted towards a partial fulfilment of the meteorologists' wish for more upper air data, and to the extent to which the data have been forthcoming, the knowledge of atmospheric processes has improved and acted beneficially on the forecasting of weather.

Upper air work in India in 1905 and 1938—a comparison.—In India, the only upper air data that were available before 1905 were ground observations from a few mountain observations and some qualitative observations of clouds. Mr. Field, the late Director-General of Observatories, started observations of upper air conditions by means of kites in 1905, and during the next three years obtained some valuable data of upper winds, temperatures and humidities over Karachi, Belgaum and a few places in the Bay of Bengal and the Arabian Sea—mainly during the monsoon months. Although the greatest height reached did not exceed 3 kilometres, some very important facts of upper air climatology were brought to light. Registration of upper air temperatures and humidities extending to greater heights by means of sounding balloons carrying instruments was commenced in 1908, first at Jhang in the N.-W. Frontier Province and later at Agra. Exploratory pilot balloon work was also commenced at about the same time and put on a systematic basis in 1914. Since then, mainly owing to the demands of aviation, pilot balloon work has increased considerably and sounding balloon work to a limited extent. Today, there are 40 pilot balloon observatories in India and Burma, and at most of them balloon ascents are made twice a day, and at a few important stations three times a day. Observations of cloud, their amounts and movements are also made at these stations. Heights of low cloud, whenever the amount exceeds 7/10ths of the sky, are measured by the height of disappearance of balloons during day. At a few selected stations, the height of low cloud

(ceiling) at night is measured by projecting a vertical beam of light by means of a searchlight and measuring its altitude from a known distance. Systematic soundings have been and are being made at Agra and Poona and occasionally at other supplementary stations such as Allahabad, Hyderabad, Madras, Bangalore, Calcutta, Ahmedabad and Trivandrum. Steps are in progress to organize a movable sounding balloon squad at Agra. Ascents of R.A.F. aeroplanes at Peshawar and Karachi are made daily or on selected days for obtaining upper air information over those places.

Use of upper air data.—We have now to consider in what way the data are utilized in weather work.

Weather forecasting being essentially the art of extrapolating weather at some future time, depends on a correct analysis of the present weather situation and a knowledge of the laws or at least the rules according to which weather changes. For both these purposes, we require in addition to surface data, such as those of pressure, temperature, humidity, etc., data relating to the upper air to as great a height as is affected during or before weather changes. In forecasting, the upper air data are always used as supplementary to the necessarily more complete surface data. Analysis of past weather has shown that major meteorological phenomena, such as the monsoons and cyclones, are associated with changes in the distribution of temperature and moisture throughout the troposphere, but owing to the increasing difficulty of obtaining data with increasing level in the atmosphere, we have for practical reasons to be satisfied with data up to 5 or 6 km. in daily weather work; we can attempt to get data at higher levels only during limited periods for study and possibly a better understanding of the laws of weather. In putting up with this limitation, we may find consolation in remembering that the moisture-content of the atmosphere decreases rapidly with height and that the main reservoir of energy of major atmospheric phenomena lies below 6 km.

In brief, the objects of collecting the aerological data are three-fold :

(i) To provide analyzed statistical material in the form of tables and maps for climatological purposes which would serve as a background of knowledge for the meteorologist and aviator.[1] When fresh problems arise such as the opening of new air-routes, routine flying at higher levels and undertaking of special experimental studies (for instance, that on cosmic rays by Millikan and Neher), these data form the indispensable basis for drawing up programmes. The analyzed data are also used for the long-range forecasting of monsoon and other rains and its improvement.

(ii) By detailed analysis of conditions in different seasons and areas and in different weather situations, to obtain a better insight of general and local circulations and of special weather phenomena such as duststorms, nor'westers, cold waves, cyclones, etc.

(iii) To furnish current information to aviators and others and to make daily forecasts of weather.

The last of these is the object that immediately appeals to the public, but (i) and (ii) are the foundations on which the structure of daily forecasting is erected.

We shall now go a little into detail regarding daily weather forecasting. The present-day meteorologist recognizes in his charts separate air-masses with different characteristic properties. Within the region of each of these air-masses, he expects different weather phenomena; for instance, in one, clear skies and marked radiation cooling at night; in another, fine but warm weather; and in yet another, cloudy weather with showers, etc. Sometimes, the region separating air-masses with markedly different properties gets narrowed down and 'fronts' are found. These fronts are surfaces inclined to the horizontal and considerable convergence and vertical movement of air take place near them, giving rise to interesting 'weather'. One of the main aims of the forecaster is to determine the positions of these fronts if they exist and determine their nature. A great help in identifying the separate air-masses is the drawing of stream-lines and trajectories of air at different levels deduced from pilot balloon and cloud movements. Information about upper air temperatures and humidities, whenever available, helps to make the identification more certain. Upper winds are also of great assistance in indicating the direction in which the disturbed area will move and the approximate rate of movement.

As examples of the use of upper air data in elucidating the structure of atmospheric disturbances may be mentioned several recent studies of storms and depressions in Indian Seas. 'Warm fronts' somewhat similar to those met with in European latitudes are associated with depressions and storms in the Bay of Bengal and the Arabian Sea in the cold season months of November to January.[2] As may be expected from the higher average temperature and specific humidity, the precipitation near the front is more intense than in the temperate latitudes. The two air-masses between which the front forms in the Bay of Bengal are the dry, cold air from north India and the moist equatorial air from the south Bay of Bengal. Upper air observations show[3] that with the approach of the storm, moist warm air first appears in the upper atmosphere and that its lower boundary gradually descends. At the same time another moist stratum which comes apparently from the middle of the Bay grows in thickness at lower levels and extends upwards. The two meet near the centre of the storm. At the back of the storm, the moist air is replaced by drier air from above.

A modified type of 'front' is associated with storms of the pre-monsoon season.[4] In this season also a front forms between the land air and the moist monsoon air. Owing to the surface heating of the land air, it is warmer in the lower levels than the moist monsoon air, but the smaller lapse-rates prevailing in the latter causes the temperatures above 3 or 4 km. to be higher in it than that in the land air. As a consequence, while the moist monsoon air tends

to behave as a cold air-mass near the ground, it behaves as warm air in the upper levels.

In monsoon depressions,[5] the main front forms between fresh monsoon air and old monsoon air, the former behaving as a cold mass and the latter as a warm mass. In N.-W. India, a comparatively drier air layer is often interposed between the westerly fresh monsoon current and the easterly old monsoon current.

The upper air data of temperature, humidity and winds required for the filling in of the details of the three-dimensional picture of tropical disturbances are yet incomplete. The only available means of gathering them in sufficient quantity is by intensive soundings with ordinary and with radio-meteorographs. A model analysis of a recent European cyclone by J. Bjerknes and E. Palmen [6] makes use of the data of 120 sounding balloon ascents carried out in three days.

Even apart from definite "fronts", it frequently happens that air-masses of different origins get superposed on one another. The configuration as such may be stable but with a small trigger action such as an upward push of the lower air by afternoon thermal convection, or dynamic convection near mountains, or onset of sea-breeze or cooling of the top of a moist layer by radiation, the equilibrium can become unstable giving rise to the development of much more kinetic energy than is conveyed to the air by the initial push.[7] Upper air data (winds, temperatures and humidities) are of invaluable assistance in diagnosing marked latent instabilities and the consequent risk of thunderstorms and squalls.

Comparison with other countries.—On the subject of upper air climatology, India has collected as good data as any country in the world, but in synoptic meteorology of the upper air we are much behind a few other countries. Our main drawbacks are the restriction of observations to a limited depth of the atmosphere and the very inadequate information that we get about the day-to-day changes of temperature and moisture in the atmosphere. In all our daily forecasting work we have to be satisfied with the tacit assumption that stream-lines and trajectories follow horizontal paths, or at best make vague guesses regarding their changes of level. For making more accurate estimates, we should prepare synoptic maps of surfaces of equal entropy and of equal saturation potential temperature. This presupposes extensive knowledge of temperature and moisture conditions in the atmosphere. As examples of countries where such work is being attempted, we may instance the United States of America and Germany. In the former country, there are 24 aeroplane stations with two ascents a day for meteorological purposes, going up to about 5 km. Owing to the limitation of the height of aeroplane ascents, the Massachusetts Institute of Technology with the assistance of the Weather Bureau and of the Bureau of Standards is proposing to change shortly from aeroplane ascents to radio-sonde ascents. These will enable data up to 15 km. to be obtained. In Germany, 10 stations take two aeroplane ascents

daily for obtaining upper air data of pressure, temperature, humidity, heights and nature of clouds, visibility in different directions, haze or dust layer boundaries and levels of bumpiness.

I hope that while we keep the practical needs of the moment in the forefront of our programme, we do not forget the necessity of continuously improving the basis of our forecasting.

REFERENCES.

[1] *Ind. Met. Dep. Sci. Notes*, Vol. 1, No. 7; Vol. 1, No. 8; Vol. 2, No. 17 and Vol. 6, No. 66.

[2] K. R. Ramanathan and A. A. Narayana Iyer, *Ind. Met. Dep. Sci. Notes*, Vol. 3, No. 18, (1930); S. Mal and B. N. Desai, *Sci. Notes*, Vol. 4, No. 39, (1931).

[3] K. R. Ramanathan, *Mem. Ind. Met. Dep.*, Vol. 26, Pt. 5, (1936).

[4] K. R. Ramanathan and H. C. Banerjee, *Ind. Met. Dep. Sci. Notes*, Vol. 4, No. 34, (1931); B. N. Desai and S. Mal, *Gerl. Beitr. Geophys.*, Vol. 40, pp. 12–17, (1933).

[5] K. R. Ramanathan and K. P. Ramakrishnan, *Mem. Ind. Met. Dep.*, Vol. 26, Pt. 2, (1933); N. K. Sur, *Ibid.*, Vol. 26, Pt. 3, (1933).

[6] J. Bjerknes and E. Palmen, Investigations of Selected European Cyclones by means of Aerial Ascents, Case 4, *Geofys. Publ.*, Vol. 12, No. 2, (1937).

[7] C. W. B. Normand, On Instability from Water Vapour, *Q. J. Roy. Met. Soc.*, Vol. 64, p. 47, (1938).

DISCUSSION.

President.—Dr. Normand, have you any remarks to make on this paper?

Dr. Normand.—I agree thoroughly that India requires more upper air observations. We have plans for an attack with meteorograph instruments on monsoon depressions and cyclones while they approach and travel across the land areas of India. This will help us to understand their structure better. Unfortunately it is difficult to draw up practical plans for a study of the interesting early stage of cyclones, which always develop over the sea. In balloon ascents over the ocean—and over the land too where we need our upper air results in time to be of use to the forecasters—a new type of instrument, the radio-sonde, will have to be used. Pioneering work with these instruments was done in Russia, Germany and elsewhere. Formerly they did not, however, give sufficiently accurate results of temperature and humidity to be of service in tropical regions. Radio-sonde methods are being intensively developed in America and in Europe at the present moment. The latest instruments have become or are becoming accurate for use in investigations in the tropics and in a year or two they may be sufficiently cheap to be brought into occasional use in India.

The President was just adjourning the session when Dr. Normand invited gentlemen present to inspect, if they cared to, two radio-sondes which were placed on the table. Dr. Normand remarked that during that day and the

previous day frequent reference had been made to radio-sondes but possibly several present had no occasion to know exactly what the radio-sonde was or did. He said that Mr. Sil or Dr. Das would demonstrate the instruments to them.

Mr. Sil then explained briefly the working of the Moltchanoff and the Vaisala radio-meteorographs.

LATENT INSTABILITY IN THE ATMOSPHERE AND ITS CONSEQUE CES.

By N. K. Sur, *Meteorological Office, Poona.*

(*Read at Symposium, July 25-26, 1938.*)

In the absence of Dr. Sur, the President called upon Dr. R. Ananthakrishnan to read the paper on "Latent Instability in the Atmosphere and its Consequences".

Dr. Ananthakrishnan.—I am glad that the absence of Dr. Sur has given me an opportunity of partaking in the Symposium. Before proceeding to give an account of the consequences of latent instability described in the present paper, I shall briefly explain what the term latent instability means. This term was introduced in meteorology by Dr. Normand about seven years ago and it implies a state of the atmosphere in which the distribution of pressure, temperature and humidity is such that energy is latent in the atmosphere and can be released by certain simple natural processes which cause the adiabatic ascent of air from lower to higher levels of the atmosphere. The idea of latent instability can be best brought out with the aid of the tephigram.

Dr. Ananthakrishnan then explained the idea of latent instability with the aid of diagrams, after which he read the paper by Dr. Sur.

1.

In the daily weather charts prepared at the Meteorological Office at Poona, lines of flow of air currents in the upper levels above ground are drawn from day to day in conformity with the direction of upper winds measured at different pilot balloon stations in India and its neighbourhood, the velocities being made use of only when trajectories are drawn for more detailed study. These lines of flow at different levels serve to show the place of origin of the winds, i.e. they help to identify different air-masses. This is of use to the forecaster, as it gives him some idea about the nature of the phenomena which can possibly occur by the interaction of the different air-masses or stream lines. We have not yet been able to collect climatological data of the upper air all over India, but a few properties of some currents of air over India in different seasons are known from available data, and in other cases are inferred from their geographical origin. For example during winter in north India cold air from regions to the north of India sweeps over Sind, Rajputana, the central parts of India, the Gangetic valley and partly over the Deccan, and we know that it is a relatively dry air-mass giving fine clear weather. But when during winter a western disturbance affects north-west India, warm humid air from the Arabian sea is drawn towards that part of India, and comes in juxtaposition

with the comparatively dry colder current. Low clouds gather over some parts of the affected region due to the flow of the humid air-mass, and rainfall may be forecasted either due to the ascent of the warmer humid air over the colder one along a warm front, or from thunderstorms along a cold front. The different currents in such extra-tropical depressions are generally identified by stream lines drawn on the charts, but data for temperature and humidity of the upper air may also be available for the north-west of India from aeroplane ascents. Similarly, when a forecast is issued for the rainfall and direction of movement of storms or depressions in the Bay of Bengal or the Arabian Sea, either in the pre- or post-monsoon seasons, or in the Bay during the monsoon season, it is based on the properties of air currents coming together to form such storms or depressions. Further, the possibility of the occurrence of thunderstorms and duststorms during summer in North India is also similarly inferred. In this note it is proposed to discuss briefly latent instability, which in India is found to be associated with all these phenomena.

2.

When a dry atmosphere is in convective equilibrium, the lapse rate of temperature is 9·8°C per kilometre, and entropy is constant throughout such an atmosphere. Usually however the lapse rate is about 6°C per km. and entropy increases with height, i.e. the layer of air having the greatest entropy is uppermost, with the layers of gradually decreasing entropy lying below in a sequence. But at any place such a condition is not constant throughout the year. Entropy may increase upwards from the ground in some seasons but decrease in others. For example, in Bengal, if we compare the wet bulb potential temperature, which is a measure of the entropy of moist air, at Darjiling (height = 2·265 km.) with that at Jalpaiguri (height = ·84 km.), on different dates chosen at random throughout a year, we find that during November–March the W.B.P.T. at Darjiling is greater than that at Jalpaiguri, while during April–October the reverse is the relation between the values of W.B.P.T. at the two places. This changed condition of the atmosphere is associated with instability during the summer and monsoon seasons.

The lapse rate of temperature in the atmosphere lies very often between those of dry and saturated adiabats. In such a case the stability or instability of the atmosphere is dependent upon relative humidity or on wet bulb temperatures. If humidity is sufficiently high in a layer or layers of air near the ground, it or these may become warmer than the environment, if raised to a suitable height, and therefore can release energy (vide fig. 1 T-ϕ gram.). A layer near A when raised up gradually, attains condensation point at H, and releases energy along JK. DF is the wet-bulb curve. Along JK the instability is manifested. To realise the energy given by the area JCK an amount of work equal to the area AHJ has to be spent on the layer at A. This type of instability has been called latent instability by Dr. Normand.[1]

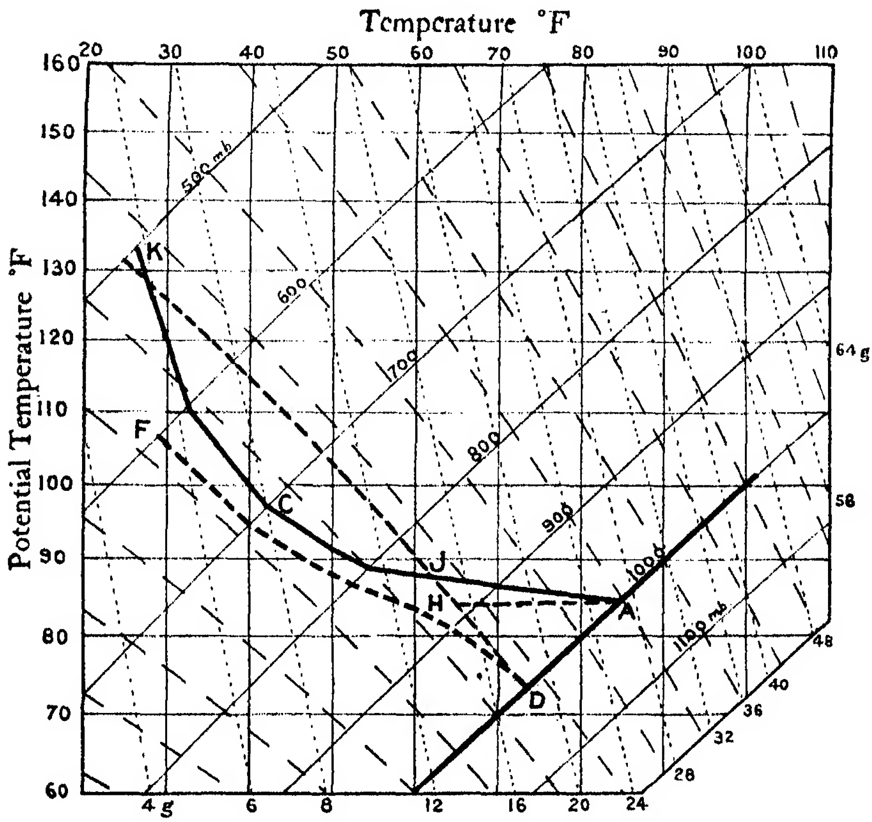


FIG. 1.

Prof. Rossby has defined a state of convective instability, in which the lapse rate of wet bulb temperature exceeds the wet adiabatic rate. For the atmosphere to have latent instability, the wet bulb potential temperature θ' at any level should exceed θ' at any higher level, and therefore it is always associated with convective instability as shown by Dr. Normand.[2] When a layer is pushed upwards adiabatically without vertical distortion, convective instability first produces latent instability, which in turn leads to instability.

With a given distribution of dry bulb temperatures in the layers of air above the ground as well as in the free atmosphere, and with a lapse rate of temperature between dry and wet adiabatics, the atmosphere may not have latent instability if the humidity is not sufficiently high.

As both the wet bulb potential and equivalent potential temperatures are measures of entropy, theoretically speaking, a decrease of E.P.T. with height is associated with convective instability; but it may or may not lead to latent instability. In India, it has been found that though E.P.T.s may decrease upwards from the ground within the first 2 or 3 km., there may be no latent

instability in the atmosphere. On the other hand an increase of E.P.T. upwards within the same layers may be followed by a subsequent decrease of E.P.T. with latent instability in the atmosphere.

3.

The conditions under which latent instability is found to exist in the atmosphere in India will now be described.

From a recent study of the tephigrams of sounding balloon ascents at Agra, Poona and Hyderabad, Mr. Sohoni and Miss Paranjpe [3] have come to the conclusion that such a type of instability is frequently developed at these places with the incursion of oceanic air of tropical or equatorial origin. At Agra latent instability is found to occur frequently during the monsoon, pre- and post-monsoon seasons, whereas at Poona and Hyderabad mostly during July–September. It is much less common during winter, when continental air generally holds sway over India. Data from soundings are not available for north-east India except during April and May. In Bengal during these two months, when Nor'westers or thunderstorms are common, latent instability is produced by the incursion of humid air from the Bay of Bengal in the first 1 or 2 km. above ground, below the dry continental air from the north-west of India and occasionally from north-east of India also. Further, from a study of duststorms at Agra [4] it has been found that these occur frequently during March–June. The frequency is maximum in May and is only slightly smaller in June. These duststorms with the associated thunderstorms are invariably preceded by the development of latent instability in the atmosphere, which is therefore believed to be a necessary condition for these to occur, though it may not be a sufficient one. Here again there is an incursion of tropical oceanic air into the region of the continental air in the north-west of India. The injection of humid air in March, April and May mostly produces duststorms and dry thunderstorms, and in June when the proportion of moisture increases, due to the gradual penetration of the S.-W. monsoon current over north India, we get more thunderstorms than duststorms at Agra, accompanied with rainfall and preceded by a high degree of latent instability.

Similarly, from a study of squalls at Karachi [5] with the aid of aeroplane data, it has been found that the occurrence of squalls is on most occasions preceded by the development of latent instability.

4.

In the storms which form in the Indian Seas during the pre-monsoon and post-monsoon seasons, it has been found that two deep air-masses from different sources and hence with different properties come together before these storms can develop. One of these is of continental origin, the other oceanic, and the storms form on the diffuse boundary of these two. These storms, which do not have a symmetrical structure, have *sometimes* sharp fronts like those of an extra-tropical depression, and their direction of movement is

believed to be the same as that of the warmer of the two air-masses between 4–8 km. These decay when the rich supply of water vapour is cut off. No sounding directly over the place of origin of such a storm is available, but it can be inferred that in such cases also latent instability is developed. For when two air-masses of different temperature and humidity flow past each other, horizontal instability is produced, as is known from the famous work of Margules. But the region of partition between two such air-masses, when one flows over the other, may also be an environment of a high degree of latent instability. This can be at once seen by plotting on a tephigram the average values of dry and wet bulb temperatures in July over Poona up to 3 km., representing the moist oceanic air, with the average Agra values above it, say up to 6 km., representing the continental air.

That such storms in the post-monsoon season may be associated with latent instability is supported by some evidence obtained in the field of a tropical cyclone.[6] On the 14th November 1933, a depression formed in the south-east of the Bay of Bengal, intensified into a storm on the 16th, and crossed the north Madras coast very near Nellore on the evening of the 17th. Some ascents were made at Madras and Poona during 15–20th November 1933. Unfortunately meteorographs let off at Madras on the evening of the 17th and on the morning of the 18th, when the centre of the storm was nearer than on any other day, were not recovered, but some information regarding latent instability in the free atmosphere over the neighbourhood of Madras has been obtained from those recovered. If the dry bulb and saturation temperatures at different heights, obtained from ascents at Madras during 15–19th November are plotted on tephigrams, the following interesting results are obtained:—

I. Denotes environment of latent instability, and
II. Layers of latent instability—

	I.	II.
15th (1716 hrs.)	Nil.	Nil.
16th (1800 hrs.)	From 460 to 310 mb. (very slight degree of latent instability).	Between 1000–720 mb.
17th (0404 hrs.)	From 800 to 170 mb.	Between 930–400 mb.
18th (1755 hrs.)	From 860 to 130 mb. (degree greater than on 17th).	Between 1000–920 mb.
19th (0400 hrs.)	No latent instability.	

It is quite clear that before the storm had affected Madras, and after it had moved away, there was no vertical instability of the latent type in the atmosphere over Madras. As it approached nearer to the place, latent instability increased gradually.

A storm in the post-monsoon season in the Arabian sea [7] may also be associated with latent instability. On the morning of 12th November 1927 a storm lay over the sea near Bombay in the south-west direction from it. Due to the storm there was a marked frontal discontinuity along a line from the centre of the storm right up to Allahabad. The discontinuity was strongly evident both in the direction and the force of the wind on the two sides of it, as well as in the type of rainfall, which extended over a belt of country 800 miles in length. The rain was caused by the ascent of warm south-easterly air from the Bay of Bengal over a north-easterly current of air. On the morning of the 13th November, the storm had crossed the Konkan Coast, and lay as a deep depression over the Bombay Deccan. Agra was far away from the centre of the depression, but an ascent on the 13th November at 1630 hrs. at Agra when it was drizzling there, shows an environment with a slight degree of latent instability between about 940–680 mb. levels, and layers of latent instability from the ground up to about 730 mb. The latent instability at Agra was in this case associated with a warm front with humid south-easterly air ascending over cold north-easterly air. The height of the warm front over Agra was about 2·8 km., and its intersection with the ground was at a distance of about 500 km. from Agra, so that its slope was about $\frac{1}{180}$.

5.

We now consider the depressions forming in the Bay of Bengal during the south-west monsoon season. A depression [8] formed on the 2nd September 1932 off the Orissa-Ganjam coast. It crossed the coast near Puri, and lay as a shallow low pressure area on the ground with its centre near Sambalpur on the morning of the 4th September. It intensified later and moved in a north-westerly direction. Its centre was near Guna in Central India both on the 6th and 7th September. It commenced to weaken on the 8th and moved past Nowgong through the southern divisions of the U.P. It disappeared by the morning of the 13th September, after persisting for a couple of days over Mainpuri near Agra in west U.P. Results of sounding balloon ascents at Agra on the 3rd, 5th, 6th, and 7th September are available. The following features regarding latent instability are noticeable:—

	I.	II.
3rd (1724 hrs.)	Nil.	Nil.
5th (1715 hrs.)	From 870–100 mb. (about).	Between 976–300 mb. (about).
6th (1720 hrs.)	From 900–100 mb. (about).	Between 978–350 mb. (about).
7th (1725 hrs.)	Practically nil, though relative humidity was 80% from ground to 6 gkm.	

It is clear that as the depression moved towards Agra, latent instability developed in the free atmosphere round about Agra, and it was wiped out when the depression weakened.

Another example of a depression during the S.-W. monsoon season developing latent instability in the region through which it passed is that of one with its centre near Puri [9] on the morning of 11th July 1937. The next morning it lay with its centre near Raipur in the Central Provinces, and on the morning of the 13th July it was over the west Central Provinces. It passed through Sambalpur in Orissa between the mornings of 11th and 12th July, and out of a number of meteorographs let off there during the passage of the depression, 4 have been recovered. These show the following features as regards latent instability:—

	I.	II.
12th (0200 hrs.)	From 840 to 400 mb. (about).	Between 980–430 mb. (about).
12th (1200 hrs.)	From 940 to above 350 mb.	Between 980–690 mb. (about) with the exception of layers between 900–835 mb.
12th (1413 hrs.)	From 920 to 810 mb. and from 750–above 350 mb.	Between 980–390 mb.
13th (0200 hrs.)	Above 500 mb.	Between 985–960 mb.

No record giving the condition of the atmosphere just before the depression approached Sambalpur is available. But it is clear from the data that there was latent instability to a marked degree in the atmosphere even just after the depression had passed away from Sambalpur; it diminished considerably on the 13th, when the depression moved further away. The reason of the increase in depth of layers with latent instability extending from 980 to 390 mb. at 1423 hrs. on the 12th as compared with those at 1200 hrs. on the same day is not clear.

6.

From the preceding discussion it would appear that latent instability should be a practically useful criterion not only for the forecasting of instability phenomena like thunderstorm and duststorm, but also of the region of rainfall along the path of depressions during all seasons in India. But this criterion can be usefully applied only if the means for its measurement from day to day be available. Aeroplane ascents and radio-sondes are the means to achieve this end. But quite a useful purpose can also be served by collecting climatological data of the upper air by the aid of soundings with Dines meteorographs. The results from these in conjunction with a knowledge of the trajectories of air currents on the daily weather charts will enable us to know the properties of different air currents in India in different seasons. This will greatly help in inferring the existence of latent instability or otherwise when two or more different streams of air are present in the upper levels over any place and therefore in forecasting the consequences of the existence of latent instability.

Attention may here be drawn to rather an important gap in our information regarding the development of latent instability in different seasons in

India. Though it is easy to see how latent instability can be produced by the injection of moist air in a mass of continental air, *e.g.* by the flow of air with properties of the S.-W. monsoon air during July at Poona extending, say, up to 2 or 3 km. above the ground below a mass of continental air, like the air over Agra in April above 2 or 3 km., it is not at all clear how in July or August the ascent of south-easterly monsoon air in the Gangetic valley represented by the air over Agra in August, above the south-westorly monsoon air from the Arabian sea represented by the air over Poona in July, can give rise to latent instability. For if the appropriate mean values of dry and wet bulb temperatures at different levels are plotted on a tephigram in the two cases respectively, latent instability is found to exist in the first case, but not in the second. It needs therefore further work to explain its development in the Gangetic valley or in Central India during the S.-W. monsoon season. Also, investigation is necessary to find the connection, if any, between the wet bulb temperatures prevailing in a given column of air having latent instability with the amount of rainfall from the column.

From an examination of about 250 sounding balloon records over Agra, Poona and Hyderabad (Deccan) and an analysis of the air-masses relating to each individual record by means of wind trajectories, Mr. Sohoni and Miss Paranjpe [3] have come to the conclusion that absence of latent instability is associated with dry fine weather with occasional high clouds of the non-convectional type, and latent instability with convective types of clouds like cumulus and cumulo-nimbus, or rain or thunder or thunderstorms. But it has been noticed that occasionally the existence of latent instability has not necessarily led to disturbed weather. Of course it is known that a suitable trigger is necessary to liberate the energy from the atmosphere having latent instability to produce a disturbance in weather, and the absence of a trigger may account for its non-occurrence. But it is not known whether in such cases, though few, the records of the upper air data are not open to doubt. If such occasions exist, a further examination of the data is necessary to find, if possible, the precise conditions under which the existence of latent instability may not result in disturbed weather.

REFERENCES.

1 C. W. B. Normand.—*Nature*, *128*, p. 583, (1931).

2 C. W. B. Normand.—*Q.J. Roy. Met. Soc.*, *64*, pp. 47–69, (1938).

3 V. V. Sohoni and Miss M. M. Paranjpe.—*Mem. Ind. Met. Dept.*, *26*, Part 7, (1937).

4 B. N. Sreenivasaiah and N. K. Sur.—*Current Science*, *6*, pp. 209–212, (1937).

5 P. R. Krishna Rao.—*Ind. Met. Dept. Sci. Notes*, *7*, No. 75, (1938).

6 K. R. Ramanathan, *Mem. Ind. Met. Dept.*, *26*, Part 5, (1936).

7 S. C. Roy and A. K. Roy.—*Beitr. Phys. freien Atmos.*, *16*, Heft 3, pp. 224–234, (1930). Data for temperature and humidity of upper air above Agra from *India Weather Review*, 1927.

* From unpublished results.

DISCUSSION.

The President: This paper is now open for discussion.

Dr. Ramanathan: During the approach of a storm, have the levels up to which latent instability extends and their variation in different phases of the storm been studied?

Dr. Ananthakrishnan: A complete quantitative study has not been made.

Dr. Roy: The temperature and the moisture content of an air-mass may be such that, although dynamically stable, it is thermodynamically unstable. The expression 'Latent Instability' is probably used by Dr. Normand in relation to such a thermodynamically unstable air-mass. Perhaps Dr. Normand will enlighten us on this point.

Mr. Basu: Latent instability, I suppose, means certain conditions in the air column irrespective of the structure. In this sense, latent instability is different from conditional instability of Rossby which is something associated with a single air-mass.

Dr. Ananthakrishnan: The term 'latent instability' merely denotes a certain vertical distribution of pressure, temperature and humidity such that the atmosphere under these conditions acts as a reservoir of latent energy, which is capable of being released by suitable means. It is not necessary to bring in the concept of air-masses to explain 'latent instability'.

Dr. Normand: It is preferable to consider each of the terms, latent, convective and conditional instability, as describing a vertical distribution of energy or entropy, irrespective of the air-masses that compose the vertical structure. If the energy of latent instability is due to one air-mass lying over another, its release tends to mix up or rearrange the masses, as in a Nor'wester.

Mr. P. R. K. Rao: In Mr. Sohoni's Memoir, latent instability was subdivided into real and pseudo-types. This division is necessary.

Dr. Ananthakrishnan: I do realise that it is; but it has not been attempted in the present paper.

Mr. Ramakrishnan: As regards quantitative study, it may be mentioned that, even at a glance, a rough idea of how significant the latent instability is can be had by seeing the thickness of the layer of latent instability and how close the environment of latent instability is to the layer. The larger the thickness of the layer, the greater the amount of energy and the nearer the environment to the layer, the easier it is to realise the energy.

RAINFALL DUE TO WINTER DISTURBANCES AND THE ASSOCIATED UPPER AIR TEMPERATURES OVER AGRA.

By S. P. VENKITESHWARAN, *Upper Air Observatory, Agra.*

(*Read at Symposium, July 25-26, 1938.*)

During January to April 1931, sounding balloon instruments were let off from Agra almost every day. The instruments retrieved gave a few sets of records of upper air temperatures and pressures for consecutive days. On a preliminary analysis [1] of the data so obtained, it was observed that during these months the day to day changes of temperature over Agra worked in opposite directions above and below the 12 km. levels; so that while temperature fell from one day to another up to the 12 km. level, above this height the temperature rose, and an inversion or a reduction in the lapse rate occurred in the region of 12 km. This type of temperature change was associated with a fall of pressure at all heights. On the other hand, while temperature rose from one day to another in the lower levels up to 12 km., above this height the temperature decreased, and the lapse rate of temperature at the 12 km. level increased. This type of temperature change was associated with a rise of pressure at all levels.

While the day to day changes of temperature at different levels between 5 or 6 km. and 12 km. were correlated with each other, the corresponding changes at levels below 5 km. did not show any definite relationship with the changes above.

However when the dry and wet bulb, etc. temperatures at levels below 6 km. were plotted from day to day on t-ϕ gram paper, they showed a more or less regular sequence which was repeated in all the four disturbances which were investigated.

The available data can be grouped into four sets:—

1. 30th January to 2nd February,
2. 5th February to 8th February,
3. 12th February to 18th February, and
4. 19th February to 23rd February.

It is observed from these sets that the day to day variation of the wet and dry bulb curves up to about 6 km. is similar in each of these sets (fig. 1). The air over Agra on the first day represented by each of these sets is dry up to 6 km. On the second day it is observed the air at the top levels has become more humid; and on the third day the thickness of this humid layer has

---

[1] *Ind. Met. Dep. Sci. Notes*, Vol. VII, No. 73.

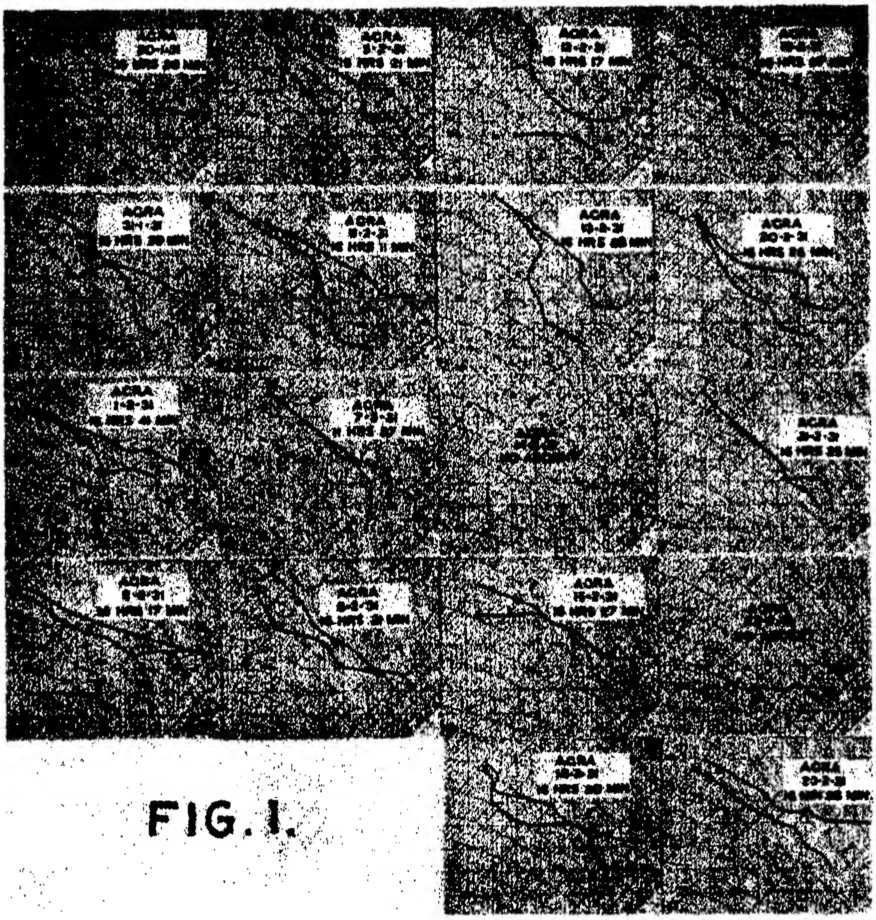


FIG. 1.

increased downwards. On the fourth day there is a tendency for drier air again to replace the humid current in the higher layers.

During these winter months the weather over N. India is mainly controlled by the passage of western disturbances. These four sets of similar temperature variations were therefore examined to see if the changes correspond to the different phases in the passage of western disturbances. For this purpose, the rainfall recorded every day at all the provincial rainfall stations within the area marked in fig. 2(a) [1] was plotted. It was observed that the maps of day to day rainfall distribution can also be divided into different sets; and the day to day distribution of rainfall during the period covered by each of these sets showed a general similarity. Each of these sets of rainfall maps

[1] The shaded areas in fig. 2 represent the regions in which rainfall occurred during the 24 hours preceding 8 a.m. on the date given on the diagram.

represents the passage of a western disturbance. It is interesting to note the daily variation of distribution of rainfall (fig. 2). The rainfall associated with

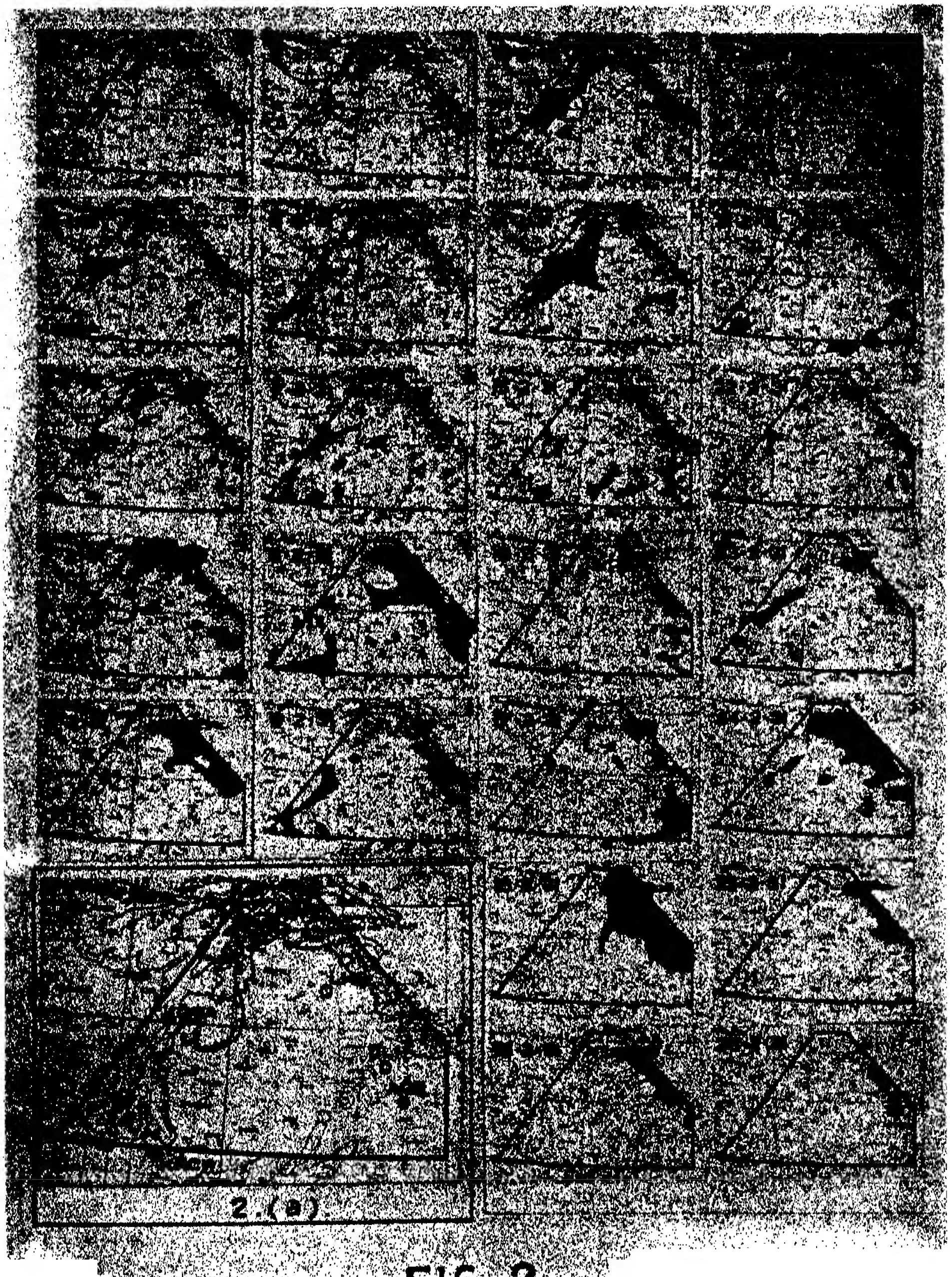


FIG. 2.

the western disturbance occurs first over the Baluchistan hills. Thereafter it occurs first on the plains of the west U.P. with slight rainfall also in the western Himalayas. Then the rainfall in the west U.P. extends towards a northerly or north-westerly direction, and the rainfall over the western Himalayas also extends westwards on the plains of the Punjab. The rainfall next decreases over the plains of the Punjab and becomes confined practically to the western Himalayas. The distribution of rainfall seems to occur in two systems, one over west U.P. and the other over the Punjab. The *westward* extension of the rainfall with the passage of a western disturbance is noteworthy; because ordinarily one would expect rain areas to extend from *west to east* with the eastward movement of the western disturbances.

It will also be seen that the distribution of rainfall in the west U.P. is similar on those days on which the soundings in the 4 series show similar distribution of temperature. It also appears that the temperature distribution over Agra is an indication, to a certain extent at least, of the rainfall distribution over the western Himalayas and the Punjab. This is natural to expect as both the day to day distribution of temperature over Agra and the day to day rainfall distribution due to the passage of western disturbances have already been shown to be similar in each disturbance.

If therefore sounding balloon data are made available every day over Agra during the winter months, either by radio-sondes, aeroplane ascents or clown balloon ascents, it may be possible to predict with fair accuracy the rainfall over west U.P. and even over east and north Punjab and the western Himalayas.

It may be useful to mention in this connection whether in the absence of sounding balloon data being available, the pilot balloon data can be utilised to indicate the properties of the air over a place by drawing trajectories for stations in and around the area under consideration. It is observed that in general the temperature distribution over the station agrees fairly well with the history of the air as indicated by the pilot balloon trajectories. When moist air is indicated by the temperature diagram at 2 km. level or higher over Agra, the trajectories also show that the air at or near about that level had travelled over the Arabian Sea. One can therefore attempt to predict the occurrence of rainfall with the help of the pilot balloon trajectories also, but this method has the handicap that the winds at all the levels may not be available when the weather is disturbed.

Discussion.

The President: This paper is now open for discussion.

Dr. Ramanathan: It is interesting to see the areas of rains extending towards the western side of the Punjab-Kumaon Hills. Although we had vague ideas about this, it is good to have brought it out so clearly. In the upper levels, the air movement is always from some west; then how is it that the rain

area spreads westwards? I wonder whether the rain-cooled air flows katabatically and is responsible for the necessary lifting which causes the rainfall, or the air which comes in the later stages of the depression has more moisture at lower levels.

I would also like to ask what is the conclusion of this study regarding the moisture content of the atmosphere below 6 km. and the temperature distribution above that level.

Mr. Venkiteshwaran: There does not seem to be any connection.

Mr. Basu: It seems to me that one point of interest to the practical forecaster has been brought out in this paper by the sequence of rainfall with approaching western disturbances in north-west India. We know that between Agra and Delhi, the upper winds are sometimes very divergent. The difficulty of extrapolating Delhi winds from Agra winds has been felt since the pilot balloon observatory at Delhi was closed during the retrenchment of 1932 but Delhi continued to be the aerodrome and we had to supply the winds for Delhi. The rainfall area near Agra branches into two, one towards the east and one towards the north-west. The moist air, whether it comes from the Bay of Bengal or from the north Arabian Sea or from any other source, and whatever its origin, arrives at about Agra in winter mainly as a south-westerly current. Here it diverges into two branches one going towards the east and the other going towards the north-west. The current over Baluchistan and the south-easterly current from Agra may meet and coalesce somewhere in the Punjab.

UPPER AIR DATA AND DAILY WEATHER FORECASTS.

By S. K. PRAMANIK, *Meteorological Office, Alipore, Calcutta.*

(*Read at Symposium, July 25-26, 1938.*)

1. Data of upper air pressures, temperatures and humidities are available from meteorograph ascents made at Agra for a large number of years, and at Poona, Hyderabad and Madras during recent years. In addition, we have also data from (1) aeroplane ascents made by the R.A.F. at Peshawar, Quetta, Karachi and a few neighbouring stations in north-west India, (2) some meteorograph ascents and kite flights at a few stations for short periods, and (3) some special meteorograph ascents during storms and disturbed weather. These data give us a fair idea of upper air pressure, temperature and humidity over north-west India and the Peninsula and are sometimes of value for a diagnostic study of the structure of cyclonic storms and the mechanism of development of thunderstorms and duststorms.

2. Upper air data obtained by the usual meteorograph ascents cannot obviously be made use of in day to day forecasting, the data so collected being available only long afterwards. For the purpose of daily forecasts these data should be obtained, as is being done at present in some countries, by arranging regular aeroplane ascents or soundings with radio meteorographs. It may be mentioned that the radio meteorographs recently developed in America appear to furnish sufficiently accurate and reliable information relating to the upper atmosphere. In the absence of a network of aerological stations in India taking daily readings of temperature and humidity in the upper atmosphere, except over parts of north-west India where data furnished by R.A.F. aeroplane ascents are of value in local forecasting, it is not possible to apply in India at present forecasting methods like those based on isentropic analysis developed by Rossby in America.

3. We have, however, in India a fairly good network of pilot balloon observatories taking two or three ascents a day, the data of which are available in time, and are found to be of great use for daily forecasting. Most of these ascents are limited in height but for practical day to day forecasting information up to 5 or 6 kms. is usually found to be sufficient. Data furnished by pilot balloon ascents give only the direction and speed of air movement at different heights and do not give any information relating to the meteorological properties of the air at those levels, although a rough idea of the latter can sometimes be obtained by drawing the trajectories of the wind and thus tracing the source from which the air originally came. The upper wind data do not also indicate whether there is any vertical movement, upward or downward, and one has generally, in the absence of this knowledge, to assume

 [Published May 4th, 1939.

only a horizontal movement. This assumption may sometimes lead to a wrong reading of the weather situation and eventually to an inaccuracy in weather forecasts. There is another drawback in having to depend upon pilot balloon ascents alone for information relating to the upper atmosphere, for these data are often not available during markedly disturbed weather and from regions close to a storm or depression when and where they are likely to be most useful.

4. Pilot balloon ascents also provide a useful method for collecting information regarding the height of base of clouds, information which is of considerable help for aviation. The surface and pilot balloon observatories in India have been reporting for some years the direction of movement of clouds, and also the height of base of low clouds from which an idea of the direction of wind at the levels of the clouds can be formed. The network of surface observatories being much closer than that of pilot balloon stations, these observations made at surface observatories about the direction of movement of clouds are of considerable help in forming an idea of the movement of air at the level of the clouds, between two pilot balloon stations and also in areas where there are no pilot balloon stations. In times of disturbed weather, surface observations are taken frequently, sometimes even at hourly intervals, but additional pilot balloon ascents are rarely taken, and as such the frequent reports of direction of movement of clouds from surface observatories help us in forming an idea of the upper air movement and its progressive variations. There is another advantage that when upper air data from pilot balloon ascents are not available owing to markedly disturbed weather or for any other reason, the direction of movement of clouds is of help in giving some idea of the upper air circulation.

5. In spite of certain limitations in the quality of information obtained by pilot balloon ascents and the availability of the data by this method, it has to be admitted that these have been of very great help in day to day forecasting in India, particularly in respect of aviation forecasts. A forecaster often can with the help of these data form an idea as to whether a depression or a storm is likely to intensify or weaken and also what the direction of its movement is likely to be. The absence of a knowledge of the actual meteorological properties of the different air-masses over a particular region and also of the nature and extent of vertical movements in these air-masses is however a handicap, and information relating to these would add greatly to the facilities that the meteorologists in India have at present for day to day forecasts of weather.

6. The charts given below will serve to illustrate the use of upper wind data in weather forecasting:—

1. *Heavy rainfall due to convergence.* (Fig. I.)

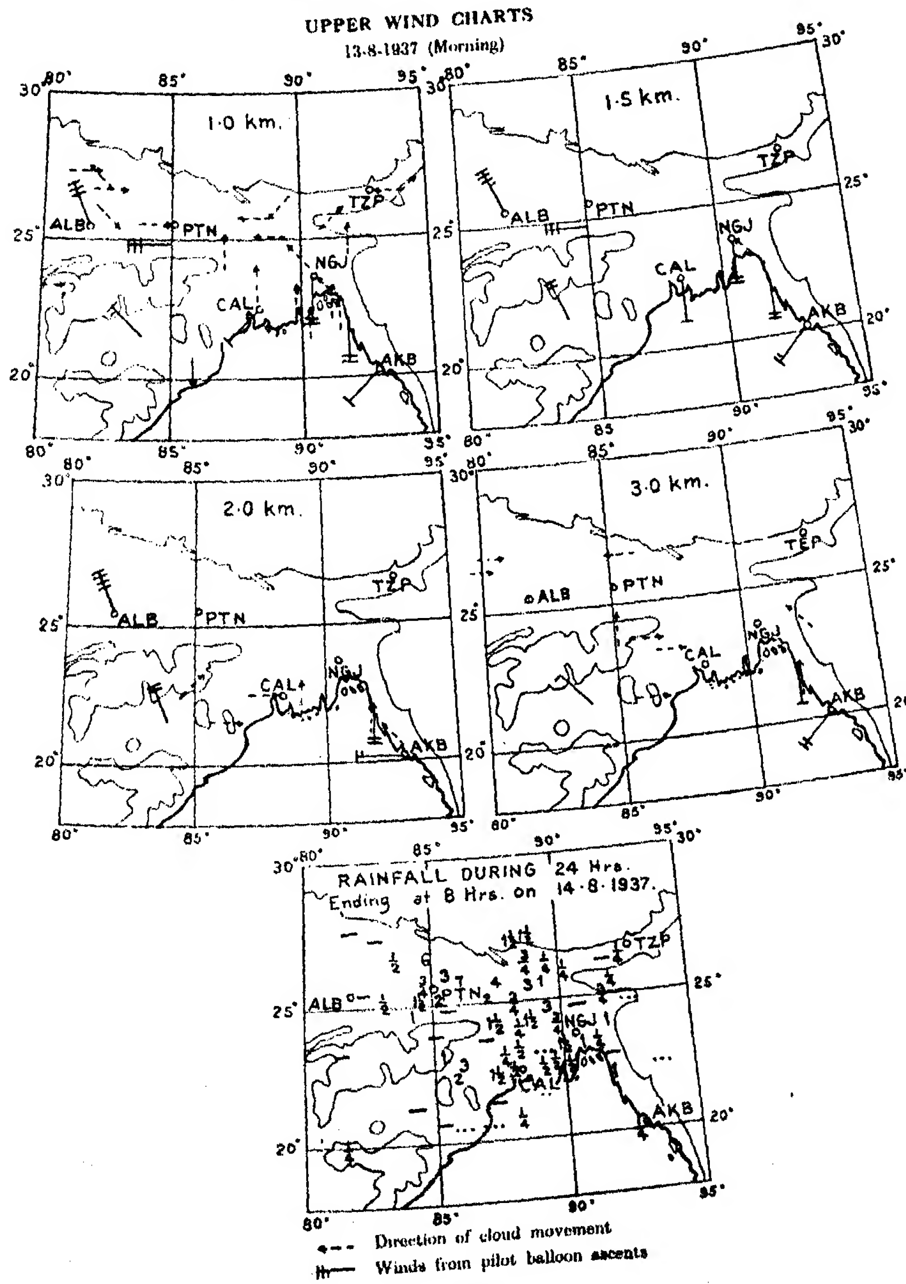
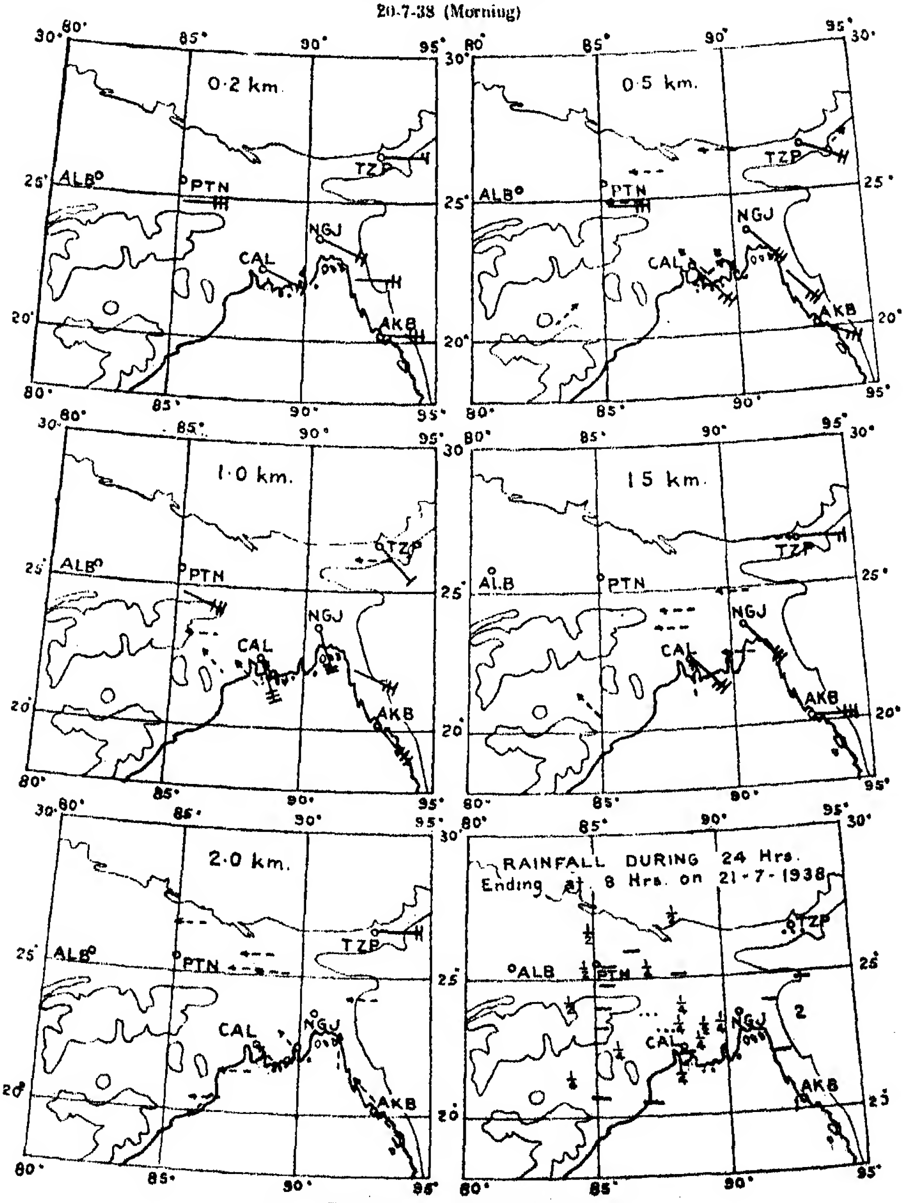


FIG. I.

2. *In the middle of the monsoon season due to unfavourable upper winds no rain falls in North Bengal.* (Fig. II.)

UPPER WIND CHARTS

20-7-38 (Morning)



←--- Direction of cloud movement

⫲— Wind from pilot balloon ascents

FIG. II.

3. *Surface conditions favourable for Nor'westers, upper air unfavourable.* (Fig. III.)

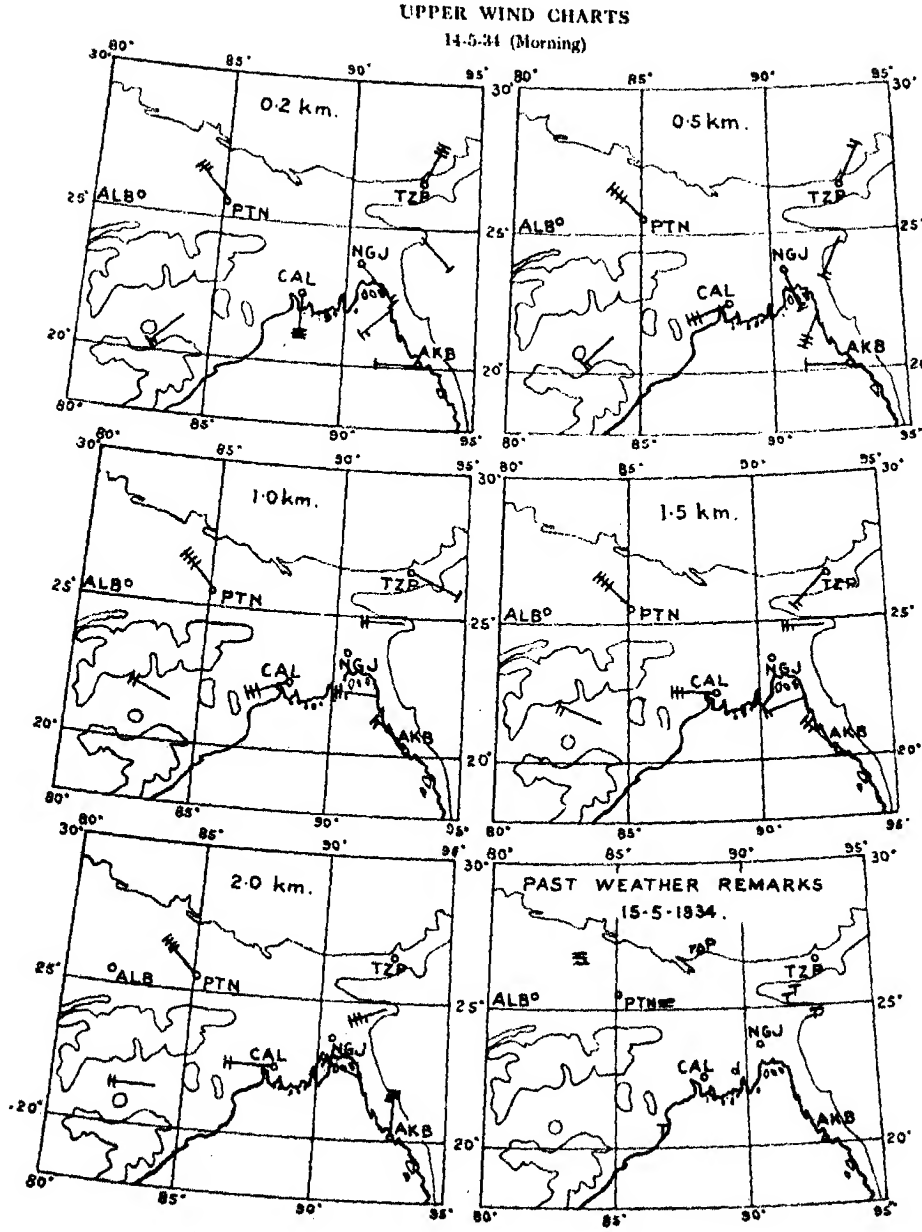


Fig. III.

There was a discontinuity in upper air from north-west Bihar to central Bengal with marked convergence of moist easterly and westerly land currents on the morning of the 13th August 1937. Very heavy rain fell along and near the discontinuity by the next morning.

The monsoon was fairly active in Assam and north Bengal on the 19th July, 1938, but the upper winds on the 20th morning showed that the moist winds had been deflected away from the region and had been replaced by dry easterly land winds with the result that there was very little rain in north Bengal and Assam during the next 24 hours.

On the 14th May 1934, morning, surface conditions appeared favourable for the occurrence of thunderstorms and nor'westers in Bengal, but the upper air conditions were unfavourable. The moist air current from the Bay was shallow and less than 0·5 km. deep at Calcutta and less than 1 km. in south-east Bengal. None of the observatories in Bengal recorded any thunderstorm or nor'wester on this day.

After reading the above paper, the author showed a few more sets of weather charts illustrating (1) decrease of rainfall with divergence in upper air currents, and with the diversion or stoppage of the supply of moist air currents and its replacement by dry land air, (2) heavy rainfall due to orography of hilly regions and their neighbourhood, and (3) occurrence of thunderstorms and nor'westers in Bengal when upper wind conditions are favourable.

Discussion.

The President: This paper is now open for discussion.

Dr. Roy: What is the character of the easterly wind at Calcutta?

Dr. Pramanik: If the easterly wind at Calcutta can be traced to have come from the Bay we consider it as moist Bay air and if we find that the upper winds in south-east Bengal do not support such a view and that the wind at Calcutta can be traced to have come from north-east Bengal or Assam we take it to be dry land air.

Mr. Doraiswamy Iyer: I would like to know whether any attempt has been made to correlate upper winds with weather 48 hours ahead. In upper air telegrams in addition to the direction the velocities are also known. Has any attempt been made to correlate subsequent weather phenomena, especially rainfall, with the wind velocities?

Dr. Pramanik: Forecasts for 48 hours have not been issued officially, but for our own use we have on some occasions tried to correlate upper winds with weather 48 hours later. In issuing forecasts both the directions and velocities of the upper winds are taken into consideration, but I have not tried to correlate weather with only the velocities.

WEATHER FORECASTING FOR AVIATION WITH SPECIAL REFERENCE TO LOCAL FORECASTS.

By P. R. KRISHNA RAO, *R.A.F. Meteorologist, Karachi.*

(Read at Symposium, July 25-26, 1938.)

It is well known that weather forecasts are of considerable importance to aviation because safety in take off, actual flight and landing, and also regularity of scheduled air service flights, depend on the weather and wind conditions experienced. The phenomena which affect safety are mainly the convectional and atmospheric obscurity phenomena experienced in the free air as well as at the landing stations on the ground. The direction and force of upper winds affect economy in flying, and also affect safety indirectly when, due to strong head winds and limited fuel capacity, forced landing becomes inevitable. Therefore, the main items of information included in aviation forecasts are: (i) cloud, together with ceiling height, (ii) visibility and the atmospheric obscurity phenomena which cause its deterioration, (iii) other adverse weather phenomena, mainly of convective type, and (iv) ground and upper winds. Forecast of cloud conditions becomes specially important for aerial reconnaisance and photography in military aviation.

Aviation forecasts may be divided into three categories: (i) regional, (ii) route, and (iii) local. Although all aviation forecasts are based, like other types of forecasts, on an analysis and study of synoptic weather maps, each of these categories has certain special problems of its own.

Regional forecasts.

In India, regional aviation forecasts are issued by the R.A.F. Meteorological Offices at Karachi and Peshawar to the R.A.F. units in north-west India. These forecasts indicate in general terms the likely weather conditions over different parts of a large area during a period of 24 hrs. The forecasts though referring to a large area are useful at any station within it for understanding the local weather changes and anticipating developments. In case of cross-country flights undertaken at very short notice, they also serve to a certain extent the purpose of route forecasts.

A typical regional forecast for Sind and Baluchistan together with local forecast for Karachi is given below:

> 'Skies mainly overcast low cloud Karachi, and 5 to 8 tenths covered cumulus strato-cumulus north-east Baluchistan afternoon with likelihood scattered thunderstorms aaa otherwise and elsewhere mainly clear aaa Local dusthaze lower Sind north Baluchistan otherwise visibility fair aaa Ground winds moderate to strong gusty W to SW lower Sind moderate

 [Published May 4th, 1939.

SE to S upper Sind and E to SE elsewhere aaa Local squalls probable afternoon north-east Baluchistan.

Local forecast—Sky mainly overcast strato-cumulus base 3,500 to 4,000 feet with slight occasional drizzle aaa Visibility fair aaa Ground wind moderate to strong gusty WSW, maximum force 25 M.P.H.'

In framing regional forecasts the development and general movement of disturbances and associated fronts require careful consideration. In this connection, the most useful aid, apart from the surface synoptic chart, is the upper wind chart at different levels. The upper wind maps with approximate isobars drawn on them, studied in comparison with similar maps at the previous routine hour of observation, give a fairly correct idea of the probable movement of disturbances and fronts. Over the hilly regions of Baluchistan and the North-West Frontier where observatories are few and tracing of fronts is not always possible, the upper wind observations are of help in understanding and judging the movement of disturbances and associated fronts.

Route forecasts.

Route forecasts require a more detailed study in view of the restricted area and the short period of a few hours to which they refer. When there are disturbances or depressions moving towards the route, a fairly correct judging of their movement and the effect such movement would produce on the weather conditions along the route during the period of flight become important. It is sometimes quite difficult to judge such movement correctly. The upper wind charts are again of considerable help in this connection because they indicate by the changes which have taken place in the direction and force of upper winds since the previous chart, the extent and the depth to which different air-masses have penetrated into the country and also the positions of surfaces of discontinuity or fronts at the different levels. An occasion where the upper wind charts as well as the surface synoptic charts showed clearly the positions of fronts at the surface and at the different levels over north India occurred in the period 14th to 17th July, 1938.

Direction of upper winds considered with surface conditions of temperature, humidity, etc. can be taken to identify the different air-masses but this is not always satisfactory. A south-east wind at Lahore at surface and even at higher levels in the monsoon season may not necessarily mean that it is moist monsoon air and sometimes rain may occur at Lahore when the upper winds at all levels are from NW. Daily aerological data, from aeroplane flights or otherwise, from representative stations are necessary to recognize the air-masses correctly and improve the forecasts. In this connection daily aeroplane meteorological flights by the R.A.F. at Karachi, Fort Sandeman, Miranshah, Peshawar, Lahore, Ambala and Delhi will be of considerable help in weather forecasting over north-west India, as they will enable construction of atmospheric vertical cross-sectional diagrams, as done in U.S.A., along the lines Karachi-Peshawar and Delhi-Peshawar.

The diurnal distribution of weather phenomena affecting aviation is of importance in route forecasting work. Over north-west India, in the summer and monsoon period, insolation appears to have considerable influence on weather. Development of cumulus clouds and thunderstorms and dust-storms occur generally after 3 P.M. and more often after 5 P.M. Rainfall unconnected with depressions generally occurs after 5 P.M. On some occasions weather may be quite suitable for flying in the morning but deteriorate in the afternoon, mainly after 3 or 4 P.M. In view of the restricted period for which route forecasts are issued, a knowledge of the 'Aviation climatology' of different parts of the day of important stations along air routes is of help in route forecasting work. On most occasions in the summer and monsoon period, fair or fine weather can be forecast over north-west India for flights in the morning hours.

The effect of mountains on the upper wind circulation is of importance for upper wind forecasts over submontane regions. It has been sometimes reported by pilots that on clear days in winter when there is a general north-west to west circulation, upper winds in the lower levels in the submontane regions are different from, and sometimes opposite to, the winds in the plains somewhat further away. Our experience with the upper wind data at lower levels from D. I. Khan and Jacobabad also shows that the effect of mountains is well marked. In view of the extensive flying by the R.A.F. in the submontane regions of the North-West Frontier and the western Himalayas, this question of the effect of mountains on upper wind circulation is one which deserves detailed examination.

Local forecasts.

Local forecasts are of importance for local flying, particularly in connection with night flying and aerial photography, for which information of cloud and visibility are specially required. They are also of use for supply to aircraft flying towards the station. For successful local forecasting a background of complete knowledge of the frequency of weather phenomena and their times of occurrence and the normal upper air temperature and humidity distribution up to about 5 Kms. appears essential.

Tephigrams drawn from the results of aeroplane meteorological flights have been found to be of use in local forecasting work at Karachi. A remarkable feature of the upper air temperature distribution over Karachi is the inversion of temperature which occurs during April to September separating a lower layer of moist air from a very much drier and potentially warmer air above. The intensity and height of base of the inversion increases with the progress of the season and is maximum in July and August. This inversion, which appears to be a direct consequence of the sharp humidity discontinuity with very dry air above moist air, acts as a barrier preventing the penetration of convectional currents from below. Owing to this inversion it may be expected that the soaring flight of gliders would not ordinarily be possible over

Karachi in the summer and monsoon period unless towed to the region above the top of the inversion, which would be about 5,000 feet in the monsoon period and about 3,000 feet in the summer period. The inversion is so well marked that the insolational warming up of the lower moist air layer cannot generally obliterate it and build up a sufficiently large lapse rate in its place for convection to continue upwards. It is for this reason that thunderstorms and duststorms due to purely local insolational convection are rare at Karachi and such phenomena therefore generally occur associated with depressions or extension of monsoon into Sind.

A general examination of the tephigrams of Karachi shows that a preliminary condition for the occurrence of any adverse weather phenomenon of the convective type during April to September is the considerable weakening or disappearance of the inversion. This condition should be considered as necessary but not sufficient, and can occur when the air-mass above the inversion is replaced by colder air or when the air below it is replaced by warmer air. The former is generally the more predominant cause.

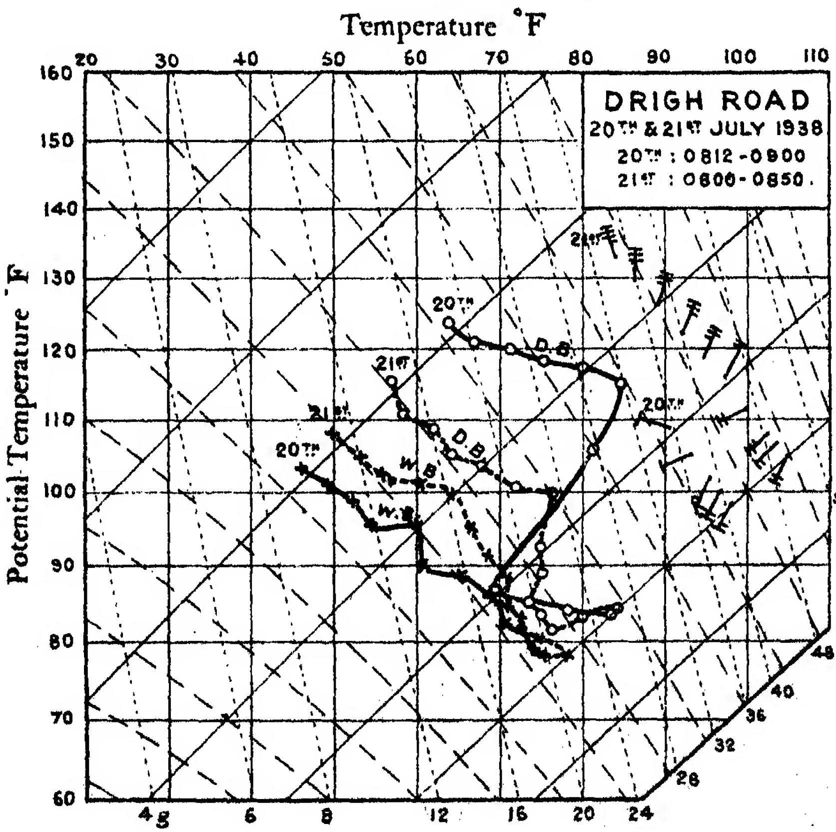


FIG. 1.

Fig. 1 shows the tephigrams and wet bulb curves on the mornings of 20th and 21st July, 1938. Above a height of about 4,000 feet there was a very well-marked fall of dry bulb and rise of wet bulb temperature between the 20th to 21st, indicating the arrival of colder and moister air. The effect of this, as is evident from the figure, was the destruction of the well-marked inversion which existed on the 20th. On the 21st morning there was, however, still an isothermal region but it is likely that with a further rapid fall of temperature and rise of humidity on the 21st conditions became unstable for rising surface air by the afternoon. Thunderstorm accompanied with moderate to heavy rain commenced at 1417 hrs. and continued till 1745 hrs. Further intermittent rain occurred in the night. Total rainfall at Drigh Road up to morning of 22nd was 3·7 inches.

The likelihood of a thunderstorm or duststorm in the afternoon can be judged by examining the morning tephigram, after taking into account the contributory effect of the afternoon insolation. In this connection the idea of latent instability introduced by Dr. C. W. B. Normand is of practical importance.

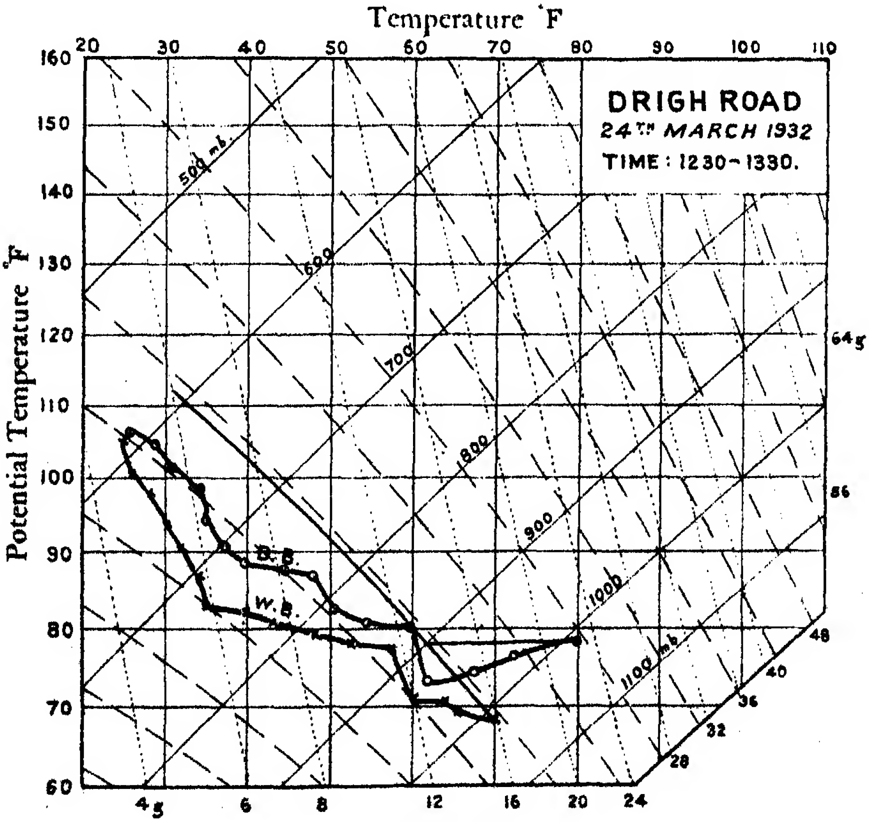


FIG. 2.

An inspection of the Karachi tephigrams shows that on days of thunderstorms or duststorms or thundery conditions, the morning tephigram at Karachi shows convective instability condition up to about 6,000 to 9,000 feet and real latent instability or actual vertical instability condition in the lower levels up to about 3,000 feet. There is great likelihood of a thunderstorm when the morning tephigram shows, after considering the effect on it of the afternoon insolation, no 'negative area' but considerable 'positive area' and the atmosphere is humid at all heights up to about 5 Kms. This is possible when the potential condensation point of surface air lies on the afternoon tephigram or to the higher temperature side of it and the portion of the tephigram at higher levels is on the lower temperature side of the saturation adiabatic drawn through the condensation point. The tephigram and wet bulb curve on the 24th March, 1932 (fig. 2) can be taken to represent a typical condition indicating considerable likelihood of thunderstorm at Karachi. They were drawn from observations of an aeroplane meteorological flight which was completed about 6 minutes before a squall with thunderstorm occurred and show a highly unstable condition for rising surface air with superadiabatic lapse rate in the first 2,000 feet. When only a duststorm occurs, the air above about 1 Km. is comparatively dry as compared to conditions prior to a thunderstorm. Thunderstorm or duststorm can be expected at Karachi if the morning tephigram, with the possible alteration in it due to afternoon insolation and expected change of air-mass or other causes, is anticipated to assume the form shown in fig. 2.

The effect of afternoon insolation on the morning tephigram is usually supposed to be due to the building up of adiabatic lapse rate up to the height corresponding to the point at which the dry adiabatic through the maximum temperature of the day meets the tephigram. At higher levels the tephigram is assumed to remain unaltered if there is no change of air-mass. When, however, there is a permanent inversion with a well-marked humidity discontinuity as over Karachi, the changes in the height of base of the inversion during the day causes changes of temperature and humidity in the inversion region which extends above the point at which dry adiabatic through the maximum temperature cuts the morning tephigrams.

At Karachi during the inversion season April to September, and specially during June to August, skies are heavily covered with stratus, strato-cumulus and cumulus, sometimes throughout the 24 hrs., and affect local flying considerably. The problem of forecasting the clearing or persistence of these clouds is therefore of importance. Some interesting papers [1, 2, 3] regarding

[1] Sverre Petterssen, On the causes and forecasting of the California fog. *Journ. Aero. Sciences*, July 1936.

[2] Irving P. Krick, Forecasting the dissipation of fog and stratus clouds. *Journ. Aero. Sciences*, July 1937.

[3] R. M. Poulter, Cloud forecasting, the daily use of the tephigram.—*Q.J. Roy. Met. Soc.*, April 1938.

forecasting of clouds by the use of aerological data have appeared in the last two years.

The chief cause of occurrence of these clouds at Karachi appears to be both radiation and convective turbulence of moist air, the latter having preponderance in the day time. This view is supported by the fact that while the clouds are formed as stratus in the late night and early morning hours, they change to strato-cumulus and cumulus in the day time. The lapse rate in the moist air-mass below the clouds is nearly the dry adiabatic in the morning and evening hours and often exceeds the dry adiabatic between 10 A.M. and 5 P.M. The appearance and clearing of clouds are closely connected with the inversion and the general temperature and humidity distribution at different hours of the day. Fig. 3 shows mean tephigrams and wet bulb temperature

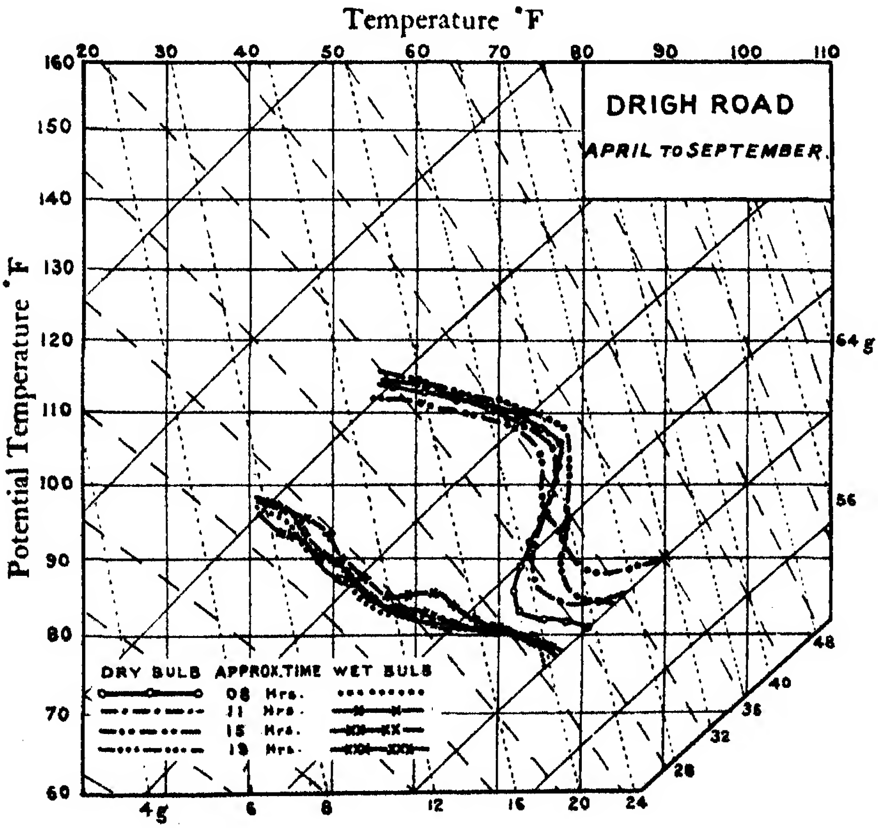


FIG. 3.

curves at different hours of the day during April to September drawn from data of some multiple meteorological flights made at Karachi. The diagram shows that the inversion level increases slightly during the morning hours

and decreases late in the afternoon and that below the inversion the lapse rate of temperature which is slightly less than the dry adiabatic rate in the morning increases with the day and becomes slightly superadiabatic in the afternoon. Clouds generally occur near the inversion, the top of the cloud layer approximately coinciding with the base of the inversion. In the day time the cloud base agrees approximately with the potential condensation level of surface air. The condensation level of surface air is directly proportional to the depression of the dew point and closely follows the diurnal variation of temperature, as the dew point has only a small diurnal variation. The variation in the height of base of inversion during the day is comparatively small and when the condensation level goes above the base of inversion clouds disappear and appear again when the returning condensation level comes below the inversion. Thus at Karachi the overcast sky in the morning clears up in the afternoon and becomes overcast again in the evening. This happens in the period April to June when the base of inversion is at a low level but in July and August when the base of inversion is high, generally above 3,000 feet, and the surface humidity is also high, the whole variation in the condensation level often occurs below the base of inversion and the sky is overcast the whole day with low cloud.

The tephigram and wet bulb curve on the morning of 16th July, 1938 (fig. 4) can be taken to be more or less typical of days in July and August on which sky is nearly overcast with low cloud throughout the day. Air rising adiabatically from the surface would follow the path BCE and would be both saturated and unstable in the stage CE. With the progress of day the condensation point would move along the isohygric CD, assuming that there is no change in absolute humidity, and till it passed beyond D rising saturated air would be warmer than the environment and cloud would exist and afterwards disappear. The surface temperature corresponding to condensation at D is F at 96°F. As the surface temperature on that day did not exceed 96°F, the whole day was clouded. The point C is often on the lower temperature side of the tephigram but even then on most occasions when the whole day is clouded the saturation adiabatic through C cuts the tephigram and the temperature corresponding to F is higher than the maximum temperature of the day. There are occasions when the saturation adiabatic through C does not cut the tephigram but is on the lower temperature side of it. In such cases if C is below the base of inversion, clouds occur if the environment is sufficiently humid but these clouds disappear when with the progress of day C goes above the base of inversion. What actually determines the time of clearance of cloud is the thickness of the layer CD which is approximately the same as the difference between the condensation level and the base of inversion.

Changes in the temperature and humidity distribution during the day, specially due to changes in the height of base of inversion, introduce some complication. Owing to this, on some occasions which occur mainly in May

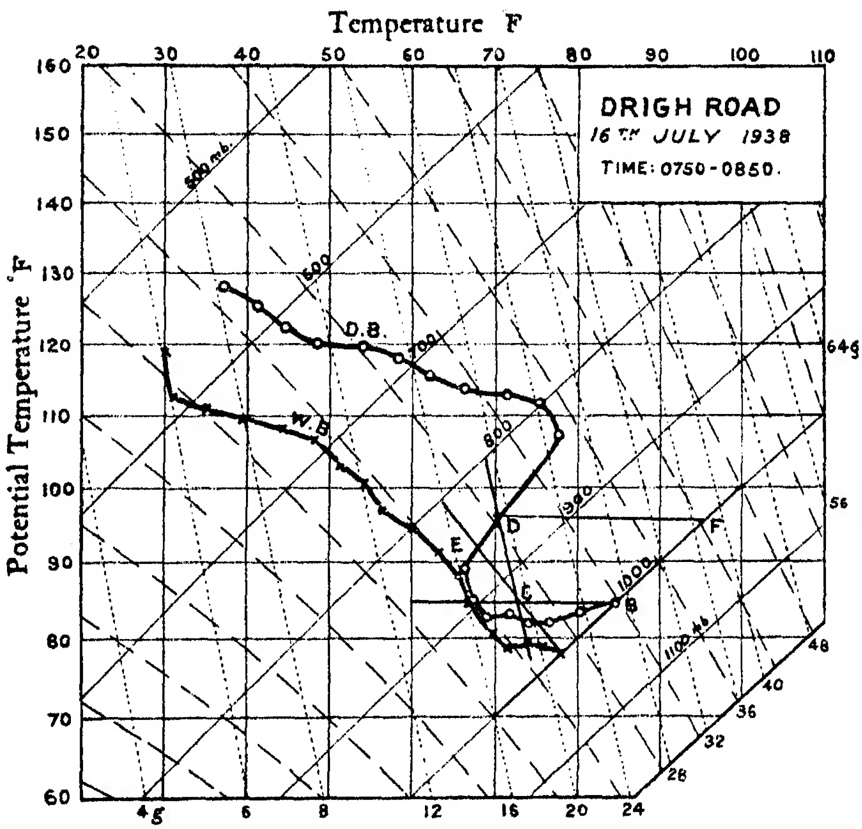


FIG. 4.

and June, while the morning tephigram may indicate clouding throughout the day, skies may be clear for sometime in the afternoon.

From the above discussion it will be seen that the morning tephigram is helpful for determining whether the whole day will be clouded or if the clouds are likely to clear, and the approximate surface temperature at which it would occur. If this temperature is less than the expected maximum temperature of the day the approximate time at which it will occur could be determined from the normal diurnal temperature variation curve for the month.

When upper air temperature and humidity data are not available, a rough approximation to the height of base of turbulence cloud during the day, *i.e.* between 10 A.M. and 5 P.M., would be the height of the condensation level of surface air. When the normal diurnal variation of depression of the dew point is known, the approximate value at any time on a particular day can be determined when its value at any other previous hour is known. It is preferable to consider the actual depression of the dew point at an evening hour, for example 2000 hrs., and from this determine the likely value at any time

during the next day by using the normal diurnal variation curve. The approximate condensation level is 1,000 feet for every 4·2°F depression of the dew point. An error of 1°F in the depression of the dew point involves an error of about 240 feet in the condensation level.

The problem of fog forecasting is also of considerable importance for aviation. There are various types of fogs but the most common is the radiation ground fog formed by the radiation cooling of air at lower levels in contact with the ground to its dew point on clear or lightly clouded nights with light winds. At Karachi Air Port, fogs occur during October to April but are not very frequent, the annual average being only about 12. An examination of a large number of fogs in previous years shows that most of them are radiation ground fogs and are generally very thick, visibility going down to 1 or 0, particularly in October-November and February-March. The only known method of forecasting radiation ground fog is an empirical one by the use of the 'Taylor diagram'. By using the 14 G.M.T. surface observation data, Taylor diagrams have been constructed for Karachi Air Port for different periods of the fog season. These diagrams do not by themselves provide a completely satisfactory method of fog forecasting but serve as an aid and have to be used in conjunction with weather charts. The diagrams have not proved quite successful in forecasting of actual occasions of fog but they have served the purpose of ruling out days when fog is unlikely whenever the point based on the evening observation is above the line.

It is considered that in the absence of daily upper air temperature and humidity data, an aid to local weather forecasting would be the classification of days in different seasons into a number of types according to the air-mass prevailing over the place as determined from surface pressure, temperature and humidity distribution and upper winds at different heights. When such a classification has been made by prior study, together with the normal weather on each type of day, the forecaster can, after determining from the evening weather chart and upper winds the type to which the following day is likely to belong, forecast the normal weather of that day. A statistical classification of local weather types on the above lines may prove of help in forecasting work.

Discussion.

The President: I wish to invite discussion on this paper.

Dr. Ramanathan: Have any ascents been made at places slightly away from Karachi? These will show the variation of the level of inversion.

Mr. Krishna Rao: It has been possible to have two simultaneous ascents at Karachi and Hyderabad. These show that the levels and intensities of the inversion at the two places are nearly the same.

(The view was expressed that ascents at some place more to the north of Karachi would give valuable information.)

KINEMATICAL METHODS IN WEATHER FORECASTING.

By S. K. BANERJI, *Meteorological Office, Poona.*

(Read at Symposium, July, 25-26, 1938.)

1. Kinematical methods can be adopted to make a forecast whenever any atmospheric process is in a state of motion. This method has been developed largely by Dedebant and Petterssen. We concentrate attention on a certain system, such as a field of pressure associated with the atmospheric process in operation, say a cyclone, a trough, a front, a wedge, etc., and the method depends on the calculation of the velocity and acceleration of representative points of the system based on the knowledge of its motion during the past few hours. If V is the velocity of an element of isobar in the direction of its normal, and A the acceleration in the same direction, then the displacement of the isobar at that point after time t is given by

$$S = Vt + \tfrac{1}{2} At^2.$$

Formulæ can also be obtained to determine whether a cyclone or a trough will be deepening or filling up during the next few hours.

The fundamental assumption involved in the calculation is that the system is moving in a continuous manner and whenever this assumption is justified, the calculation gives, with a considerable degree of accuracy, the displaced position of the isobaric system after the lapse of a few hours, provided the velocity and acceleration have been calculated on the data of the previous two or three hours.

2. *Velocity and Acceleration of a Characteristic Curve.*

If an entity (say, the pressure), which is a function of the co-ordinates and time, namely, $F(x, y, t)$, is in a state of motion, then at time $t + \delta t$, its value is given by $F(x+u\delta t, y+v\delta t, t+\delta t)$, or,

$$F + u\delta t \frac{\partial F}{\partial x} + v\delta t \frac{\partial F}{\partial y} + \delta t \frac{\partial F}{\partial t}.$$

u and v being the components of velocity. This is also equal to

$$F + \frac{DF}{Dt}\delta t.$$

Therefore,

$$\frac{DF}{Dt} = \frac{\partial F}{\partial t} + u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y}.$$

Let us consider the movement of an isobar. It is a characteristic curve, whose equation can be written in the form

$$p = p(x, y, t) = \text{constant} = C, \quad (C = p_1, p_2, \text{etc.})$$

The displacement of an element of the curve tangential to the curve itself is of no consequence so far as the future position of the isobar is concerned.

To find the rate of motion (V) of the curve normal to itself we get at time $t+\delta t$,

$$p(x+lV\delta t,\ y+mV\delta t,\ t+\delta t) = C,$$

where l, m are the direction cosines of the normal at (x, y). Therefore,

$$V\left(l\frac{\partial p}{\partial x}+m\frac{\partial p}{\partial y}\right)+\frac{\partial p}{\partial t}=0,$$

or,

$$V\frac{\partial p}{\partial n}+\frac{\partial p}{\partial t}=0,$$

where δn is an element of the normal to the curve at (x, y). We thus get

$$V = -\frac{\partial p}{\partial t}\Big/\frac{\partial p}{\partial n}.$$

Thus, the velocity is equal to minus the barometric tendency divided by the pressure gradient. We can also express the result in the form

$$V = -Th,$$

T being the barometric tendency, and h the distance between two neighbouring unit isobars. The velocity of an isobar normal to itself is thus equal to minus the tendency multiplied by the distance between two neighbouring unit isobars. If the normal is drawn in the direction in which the gradient is positive, then an isobar moves in the direction of the normal if pressure is falling with time in that direction; if pressure is rising with time then it moves in the opposite direction. The velocity is greater the greater the tendency or the smaller the gradient. Other things being equal, a shallow depression moves with a greater velocity than a deep one.

3. *Acceleration of isobars.*

If the x-axis coincides with the direction of the normal, we have

$$\frac{D}{Dt}=\frac{\partial}{\partial t}+V\frac{\partial}{\partial x}.$$

Therefore, acceleration

$$A=\frac{DV}{Dt}=\frac{\partial V}{\partial t}+V\frac{\partial V}{\partial x}$$

and

$$\frac{D^2}{Dt^2}=\left(\frac{\partial}{\partial t}+V\frac{\partial}{\partial x}\right)\left(\frac{\partial}{\partial t}+V\frac{\partial}{\partial x}\right)$$

$$=\frac{\partial^2}{\partial t^2}+2V\frac{\partial^2}{\partial x\partial t}+V^2\frac{\partial^2}{\partial x^2}+A\frac{\partial}{\partial x}.$$

Now, taking the characteristic curve

$$p\ (x, y, t) = \text{constant},$$

we see at once that in a system of co-ordinates that move with the curve element in question

$$\frac{Dp}{Dt} = 0, \quad \frac{D^2p}{Dt^2} = 0$$

$$\therefore \quad \frac{\partial p}{\partial t} + V\frac{\partial p}{\partial x} = 0,$$

$$\text{and} \quad \frac{\partial^2 p}{\partial t^2} + 2V\frac{\partial^2 p}{\partial x \partial t} + V^2\frac{\partial^2 p}{\partial x^2} + A\frac{\partial p}{\partial x} = 0.$$

We thus get

$$A = -\left(\frac{\partial^2 p}{\partial t^2} + 2V\frac{\partial^2 p}{\partial x \partial t} + V^2\frac{\partial^2 p}{\partial x^2}\right) \Big/ \frac{\partial p}{\partial x}.$$

4. *Motion of a centre of a cyclone or an anticyclone.*

At the centre of a cyclone or an anticyclone, the pressure is minimum or maximum respectively. Therefore, the characteristic property of the centre is given by

$$\frac{\partial p}{\partial x} = 0, \quad \frac{\partial p}{\partial y} = 0,$$

coupled with the condition

$$\frac{\partial^2 p}{\partial x^2} \gtrless 0, \quad \frac{\partial^2 p}{\partial y^2} \gtrless 0.$$

If V_x, V_y denote the components of velocity of the centre in the directions of axes of x and y, we get by treating the above characteristic equations in the same way as we treated the other characteristic curves,

$$V_x = -\frac{\partial^2 p}{\partial x \partial t} \Big/ \frac{\partial^2 p}{\partial x^2}, \quad V_y = -\frac{\partial^2 p}{\partial y \partial t} \Big/ \frac{\partial^2 p}{\partial y^2}.$$

The velocity of the pressure centre is, therefore, proportional to the isallobaric gradient and inversely proportional to the steepness of the pressure profile.

The components of acceleration (A_x, A_y) are easily shown to be

$$A_x = -\left(\frac{\partial^3 p}{\partial x \partial t^2}\frac{\partial^2 p}{\partial x^2} - 2\frac{\partial^2 p}{\partial x \partial t}\cdot\frac{\partial^3 p}{\partial x^2 \partial t}\right) \Big/ \left(\frac{\partial^2 p}{\partial x^2}\right)^2,$$

$$A_y = -\left(\frac{\partial^3 p}{\partial y \partial t^2}\frac{\partial^2 p}{\partial y^2} - 2\frac{\partial^2 p}{\partial y \partial t}\cdot\frac{\partial^3 p}{\partial y^2 \partial t}\right) \Big/ \left(\frac{\partial^2 p}{\partial y^2}\right)^2.$$

5. *Movement of trough lines.*

The pressure distribution exhibits a trough or a wedge when the isobars are curved in such a way that there is maximum of curvature along a line in the pressure field. If the trough line is taken as the y-axis and a line perpendicular to it as the x-axis, the trough line is characterized by the following conditions :—

$$\frac{\partial p}{\partial x} = 0 \quad \text{and} \quad \frac{\partial^2 p}{\partial x^2} \gtrless 0.$$

Therefore the velocity of any point of the trough line normal to itself is

$$V_x = -\frac{\partial^2 p}{\partial x \partial t} \Big/ \frac{\partial^2 p}{\partial x^2}.$$

In a similar manner we can determine the acceleration of the trough line.

6. *Movement of Fronts.*

A front may be defined as the line of intersection between a surface of discontinuity and a horizontal plane at the ground or in the free atmosphere. The surface of discontinuity, which is supposed to be the surface of separation between two air-masses of different densities, is of finite thickness and is inclined at a definite angle to the horizon depending on the difference of the densities.

If θ denotes the inclination of the frontal surface to the horizon, we have according to the well-known formula,

$$\frac{\partial p_1}{\partial x} - \frac{\partial p_2}{\partial x} = -g(\rho_1 - \rho_2)\tan\theta,$$

ρ_1, ρ_2 being the densities of the air-masses. So long as a front maintains its characteristic existence ρ_1 is never equal to ρ_2. Therefore $\frac{\partial p_1}{\partial x}$ is never equal to $\frac{\partial p_2}{\partial x}$.

At the surface of discontinuity the following conditions must be satisfied:—

(1) The pressure on either side of the surface must be equal, but not the pressure gradients.

(2) The velocity components normal to the surface must be equal on both sides.

If p_1 and p_2 be the values of pressure at two points on either side of an element of a front, we have

$$p_1 - p_2 = 0, \ (\rho_1 - \rho_2) = 0.$$

Treating this equation in the same way as any other characteristic curve, we find that the velocity of the front in the direction of the x-axis is given by

$$V = -\left(\frac{\partial p_1}{\partial t} - \frac{\partial p_2}{\partial t}\right) \Big/ \left(\frac{\partial p_1}{\partial x} - \frac{\partial p_2}{\partial x}\right).$$

The velocity is greater the greater is the difference between the tendencies on the two sides of the front, and the smaller is the difference between the pressure gradients. A front is stationary only when

$$\frac{\partial p_1}{\partial t} = \frac{\partial p_2}{\partial t}$$

or the tendencies are equal on both sides of the front.

The analytical expression given below for the acceleration of fronts may be deduced on general principles

$$A=\left[\left(\frac{\partial^2 p_1}{\partial t^2}-\frac{\partial^2 p_2}{\partial t^2}\right)+2V\left(\frac{\partial^2 p_1}{\partial x\partial t}-\frac{\partial^2 p_2}{\partial x\partial t}\right)+V^2\left(\frac{\partial^2 p_1}{\partial x^2}-\frac{\partial^2 p_2}{\partial x^2}\right)\right]\Big/\left(\frac{\partial p_1}{\partial x}-\frac{\partial p_2}{\partial x}\right).$$

There are considerable difficulties in computing the acceleration of fronts. These arise on account of the fact that the quantities which have to be put in the formulæ have to be taken from the immediate vicinity of the fronts.

In order to avoid confusion, let index 1 denote the cold air in front of the warm front, index 2 the warm air in the rear of the warm front, index 3 the warm air in front of the cold front, and index 4 the cold air in the rear of the cold front.

Let V_w and V_c denote the velocities of the warm and cold fronts respectively. Then

$$V_w=-\left(\frac{\partial p_1}{\partial t}-\frac{\partial p_2}{\partial t}\right)\Big/\left(\frac{\partial p_1}{\partial x}-\frac{\partial p_2}{\partial x}\right),\quad V_c=-\left(\frac{\partial p_3}{\partial t}-\frac{\partial p_4}{\partial t}\right)\Big/\left(\frac{\partial p_3}{\partial x}-\frac{\partial p_4}{\partial x}\right).$$

If the x-axis coincide with the direction of isobars in the warm sector, we have

$$\frac{\partial p_2}{\partial x}=\frac{\partial p_3}{\partial x}=0.$$

Assuming the front and the rear of the cyclone to be symmetrical with regard to pressure distribution, we get

$$\frac{\partial p_1}{\partial x}=-\frac{\partial p_4}{\partial x}>0.$$

Subtracting V_w from V_c, we get

$$V_c-V_w=\left(\frac{\partial p_1}{\partial t}-\frac{\partial p_2}{\partial t}-\frac{\partial p_3}{\partial t}+\frac{\partial p_4}{\partial t}\right)\Big/\frac{\partial p_1}{\partial x}.$$

which is a measure of the rate at which the cold front overtakes the warm front. From this we see that a negative tendency in the warm sector is favourable for occlusion. If the rise of pressure behind the cold front, *i.e.* $\frac{\partial p_4}{\partial t}$, is greater than the fall of pressure in front of the warm front, *i.e.* $\frac{\partial p_1}{\partial t}$, we also have favourable conditions for occlusion.

7. *Deepening and filling up of a depression.*

Deepening or filling refers to the pressure in a moving system of co-ordinates which is fixed to the moving pressure system. The connection between the pressure variation in a moving system of co-ordinates and a fixed system is given by

$$\frac{Dp}{Dt}=\frac{\partial p}{\partial t}+V\,.\,\nabla p.$$

This equation shows that the pressure variation at a fixed station is composed of two parts: (1) one which is caused by the movement of the pressure system, and (2) one which is caused by the deepening or filling. By computing Dp/Dt for a number of points and by suitable interpolation, the change in structure of the moving pressure system may be calculated. In a moving system of co-ordinates, the pressure variation when expanded in a Maclaurin's series is given by

$$\Delta p = \left(\frac{Dp}{Dt}\right)_0 . t + \frac{1}{2}\left(\frac{D^2p}{Dt^2}\right)_0 . t^2,$$

where terms of third and higher orders have been neglected.

This expression is equivalent to

$$\Delta p = \left(\frac{\partial p}{\partial t} + V . \nabla p\right)_0 t + \frac{1}{2}\left[\frac{\partial^2 p}{\partial t^2} + 2V . \nabla \frac{\partial p}{\partial t} + \frac{\partial V}{\partial t} . \nabla p + V . \nabla(V . \nabla p)\right]_0 t^2$$

and at a pressure centre, where $\nabla p = 0$, it reduces to

$$\Delta p = \left(\frac{\partial p}{\partial t}\right)_0 . t + \frac{1}{2}\left[\frac{\partial^2 p}{\partial t^2} + 2V_x \frac{\partial^2 p}{\partial x \partial t} + 2V_y \frac{\partial^2 p}{\partial y \partial t} + V_x^2 \frac{\partial^2 p}{\partial x^2} + V_y^2 \frac{\partial^2 p}{\partial y^2}\right]_0 t^2$$
$$+ V_x V_y \left(\frac{\partial^2 p}{\partial x \partial y}\right)_0 t^2.$$

When the axes are chosen to be the two lines along which there is either maximum or minimum of curvature of the pressure profiles, the last term vanishes. The integral of deepening or filling per unit time over a surface is given by—

$$\int \frac{Dp}{Dt} d\sigma = \int \frac{\partial p}{\partial t} d\sigma + \int V_c \nabla p d\sigma.$$

If i, j, be unit vectors and i coincides with ∇p, we have

$$\nabla p = \frac{\partial p}{\partial h} i.$$

If $dp = 1$, then dh is the distance between unit isobars. Also—

$$d\sigma = dh . ds,$$

ds being an element of length of isobar.

Therefore

$$\int V_c \nabla p \, d\sigma = \int V_c i \, ds = V_c i \int ds = 0.$$

Hence
$$\int \frac{Dp}{Dt} d\sigma = \int \frac{\partial p}{\partial t} d\sigma. \quad .. \quad .. \quad .. \quad .. \quad (1)$$

The deepening or filling over the area between two closed isobars is, therefore, equal to the planimetric value of the barometric tendency in the same area.

In a system of co-ordinates fixed to a moving isobar

$$\frac{Dp}{Dt} = 0.$$

Therefore $$\frac{\partial p}{\partial t} = -V \cdot \nabla p.$$

Hence $$\int \frac{\partial p}{\partial t}\, d\sigma = -\int V\, \nabla p\, d\sigma = -\int V i ds = -\frac{dA}{dt} \quad .. \quad .. \quad (2)$$

where A is the area enclosed by the isobar.

Combining (1) and (2), we get

$$\int \frac{Dp}{Dt}\, d\sigma = -\frac{dA}{dt}.$$

Therefore, when the area enclosed by a closed isobar is contracting, the depression is deepening and when the area is expanding it is filling up.

8. *Methods of numerical evaluation.*

The axes of x and y are drawn in the directions of maximum and minimum curvature respectively of pressure profiles. They need not be at right angles or straight lines. The expressions give the velocity and acceleration at the origin in the directions of the axes. With a suitable choice of units, we have

$\dfrac{\partial^2 p}{\partial t^2} = T_1 - T_0 =$ difference between two consecutive values (three-hourly) of barometric tendency,

or, $\dfrac{\partial^2 p}{\partial t^2} = (p_2 - p_1) - (p_1 - p_0)$,

p_0, p_1, p_2, being three consecutive pressure observations.

$$\frac{\partial^2 p}{\partial x\, \partial t} = \frac{\left(\dfrac{\partial p}{\partial t}\right)_1 - \left(\dfrac{\partial p}{\partial t}\right)_2}{\delta x} = \frac{1}{H_x},$$

where H_x is the distance between the points of intersection of x-axis (which is normal to isobars) and two consecutive unit isallobars.

$\dfrac{\partial^2 p}{\partial x^2} =$ curvature of the pressure profile in the direction of the x-axis.

It is easy also to see with reference to Fig. 1 that the values of the different differential coefficients can also be obtained from the following expressions:—

$$\frac{\partial^2 p}{\partial x \partial t} = T^{\frac{1}{2},\, 0} - T^{-\frac{1}{2},\, 0} = \frac{1}{2}\left(T^{1,\, 0} - T^{-1,\, 0}\right)$$

$$\frac{\partial^2 p}{\partial x^2} = p^{1,\, 0} - 2p^{0,\, 0} + p^{-1,\, 0}$$

$$\frac{\partial^3 p}{\partial x \partial t^2} = \Delta T^{\frac{1}{2},\, 0} - \Delta T^{-\frac{1}{2},\, 0} = \frac{1}{2}\left(\Delta T^{1,\, 0} - \Delta T^{-1,\, 0}\right)$$

$$\frac{\partial^3 p}{\partial x^2 \partial t} = T^{1,\, 0} - 2T^{0,\, 0} + T^{-1,\, 0}.$$

Similarly for $\frac{\partial^2 p}{\partial y \partial t}$, $\frac{\partial^2 p}{\partial y^2}$, etc.

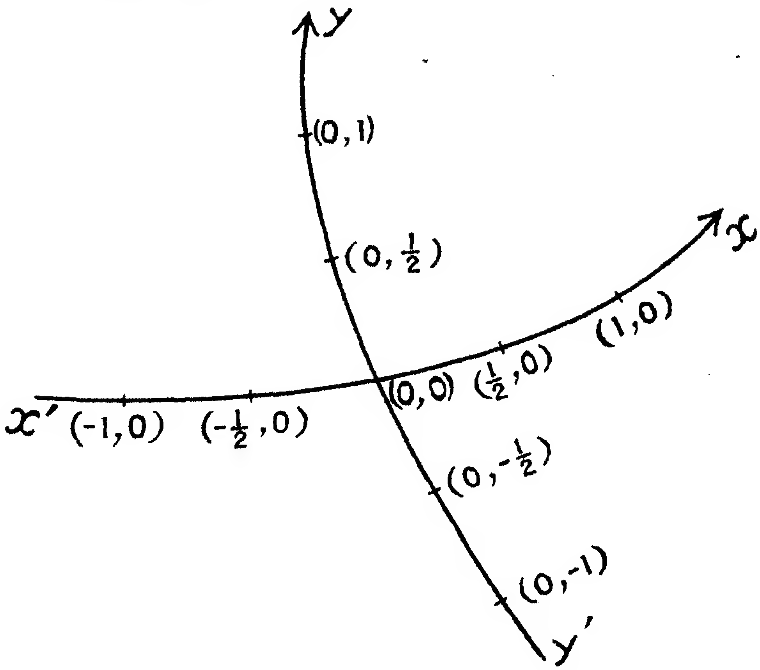


FIG. 1.

The formulæ to be used in any specific instance will depend on the data available.

9. *Numerical Evaluation. Order of quantities.*

Let us first consider a hypothetical case. Let Burdwan be on the isobar 29·700 at 8 hrs. and let the normal to the isobar pass through Calcutta and Asansol. Let us calculate the velocity and the acceleration of this isobar at Burdwan. Let us suppose that the following pressure observations are available:—

		Calcutta.	Burdwan.	Asansol.
Pressure at 2 hrs.	..	29·728	29·713	29·704
Pressure at 5 hrs.	..	29·723	29·707	29·698
Pressure at 8 hrs.	..	29·715	29·700	29·690

Distance between Calcutta and Burdwan = 60 miles.

,, ,, Burdwan and Asansol = 50 miles.

Mean pressure gradient at 8 hrs. at Burdwan (units: pressure in thousandth part of an inch and distance in miles)

$$= \frac{1}{2}\left(\frac{15}{60}+\frac{10}{50}\right) = \frac{9}{40}.$$

Rate of change of pressure at Burdwan is 7 in three hours. Therefore the velocity of the isobar at Burdwan is

$$= 7 \times \frac{40}{9} \text{ miles in 3 hours}$$

or about 10 miles per hour.

[If the value of the rate of change of pressure at an individual station is doubtful, we can take the mean of the rates of change at the station and neighbouring stations to obtain an approximation. In this case the mean of the rates of change at Calcutta, Burdwan and Asansol is also about 7 in 3 hours.]

At Burdwan, the value of $\frac{\partial^2 p}{\partial t^2}$ is $\frac{1}{9}$ per hour per hour, at Calcutta it is $\frac{3}{9}$ per hour per hour and at Asansol $\frac{2}{9}$ per hour per hour. If there is a barograph at Burdwan, then $\frac{\partial^2 p}{\partial t^2}$ at that station is given by the curvature of the barogram at that station. In the absence of a barograph, an approximate value of $\frac{\partial^2 p}{\partial t^2}$ is obtained by taking the mean of the values of this quantity at the 3 stations. The value of $\frac{\partial^2 p}{\partial t^2}$ is therefore $\frac{2}{9}$ per hour per hour.

The value of $\frac{\partial^2 p}{\partial x \partial t}$ at Burdwan

$$= \frac{1}{2}\left[\frac{\left(\frac{\partial p}{\partial t}\right)_{\text{Cal.}} - \left(\frac{\partial p}{\partial t}\right)_{\text{Bur.}}}{60} + \frac{\left(\frac{\partial p}{\partial t}\right)_{\text{Bur.}} - \left(\frac{\partial p}{\partial t}\right)_{\text{Asan.}}}{50}\right]$$

$$= \frac{1}{2}\left[\frac{8-7}{60} + \frac{7-8}{50}\right] = -\frac{1}{600} \text{ in 3 hours}$$

$$= -\frac{1}{1800} \text{ per mile per hour.}$$

$\frac{\partial^2 p}{\partial x^2}$ is the curvature of the pressure profile along the x-axis. In the present case, we can attribute the gradient $\frac{15}{60}$ to the midpoint between Calcutta and Burdwan and the gradient $\frac{10}{50}$ to the midpoint between Burdwan and Asansol.

Therefore $$\frac{\partial^2 p}{\partial x^2} = \frac{1}{30+25}\left[\frac{15}{60} - \frac{10}{50}\right] = \frac{1}{1100}.$$

Therefore the acceleration of the isobar at Burdwan

$$= -\frac{40}{9}\left[\frac{2}{9} - 2 \times 10 \times \frac{1}{1800} + 10^2 \cdot \frac{1}{1100}\right]$$

$$= -1{\cdot}3 \text{ miles per hour per hour.}$$

The magnitude of the acceleration is usually of a smaller order than that of the velocity.

10. *Application to Indian Charts.*

For the calculation of the velocity and acceleration we need charts at least every 3 hours. In India, this is not available under normal conditions. When there is a storm at sea, special charts are prepared every 12 hours or every 6 hours and occasionally every 3 hours, but unfortunately even in these cases the data available for the sea areas are quite inadequate for the application of the method.

In the following examples, therefore, no attempt is made to determine the acceleration term. In one or two cases, only the order of the quantity involved will be indicated.

(*a*) *Storm of October* 31—*November* 2, 1927. (Figs. 2–9.)

The track had an abrupt curvature between 8 hrs. and 18 hrs. of 2nd November and it is of interest to know whether the calculation of the velocities of the centre of the storm would indicate the curvature. Fig. 2 gives the track of the storm. The isobaric and the isallobaric charts on which the calculation is based are given in Figs. 5, 6 and 9.

Taking the isobaric chart for 1st November (8 hrs.), we see that the gradient at Madras is a 0·050 inch in 50 miles and the tendency is ·012 inch per hour. Therefore the velocity of the isobar is 12 miles per hour.

The velocity of the centre—

$$V_x = -\frac{\partial^2 p}{\partial x \partial t}\Big/\frac{\partial^2 p}{\partial x^2} = \frac{10}{100}\Big/\frac{1}{120} = 12 \text{ miles per hour}$$

$$V_y = \frac{10}{110}\Big/\frac{1}{130} = 12 \text{ miles per hour.}$$

In these cases it is simpler to get the values of $\frac{\partial^2 p}{\partial x^2}$ and $\frac{\partial^2 p}{\partial y^2}$ from the curvature of the pressure profile (Figs. 4, 5). It will be observed that the calculation of the velocity depends on a correct determination or an accurate estimate of the pressure profile along the axes.

With the velocity given above, the centre moved from position A at 8 hrs. to position B at 15 hrs. (Fig. 5).

On the 2nd November, at 8 hrs—

$$V_x = \frac{50}{20\times 5}\Big/\frac{1}{17} = 8{\cdot}5 \text{ miles/hr.}, \quad V_y = \frac{50}{30\times 5}\Big/\frac{1}{30} = 10 \text{ miles/hr.}$$

$$\therefore\ V = \left(V_x^2 + V_y^2\right)^{\frac{1}{2}} = 13{\cdot}2 \text{ miles/hr.}$$

The actual movement in the next six hours was 80 miles. By plotting these velocities in fig. 9, it is at once seen that there was a change in curvature in the track of the storm at this time.

We have in this case, roughly,

$$\frac{\partial^2 p}{\partial y^2} = \frac{1}{30}, \quad \frac{\partial^3 p}{\partial y \partial t^2} = \frac{1}{20}, \quad \frac{\partial^2 p}{\partial y \partial t} = \frac{1}{20}, \quad \frac{\partial^3 p}{\partial y^2 \partial t} = \frac{1}{30}$$

Therefore $A_y = \frac{3}{2}$ miles per hour per hour.

This gives roughly the order of the acceleration term.

From the 3 hrs. chart of 2nd November, 1927 we see that the planimetric value of the tendency within the isobar 29·600 in. is about —·015 in. per unit area per hour. This means that the depression will be deepening at the rate of —·015 in. per hour. Therefore during the next 5 hours the deepening will be ·075 in. Actual deepening was ·100 in. The lower calculated value is due to an under-estimate of the tendency values, the estimate being based on observations taken at 17 hrs. of 1st November, 1927 and 3 hrs. of 2nd November, 1927.

(*b*) *Storm of November* 12–20, 1923. (Figs. 10–23.)

Charts were prepared at intervals of 12 hours. From these (Figs. 12, 15, 16, 21), we get the following values of the velocities:—

November 13, 8 hours $\begin{cases} V_x = \dfrac{10}{30\times 12} \Big/ \dfrac{1}{140} = 4 \text{ miles/hour.} \\ V_y = \dfrac{10}{30\times 12} \Big/ \dfrac{1}{150} = 4{\cdot}2 \text{ miles/hour.} \end{cases}$

November 14, 8 hours $\begin{cases} V_x = \dfrac{10}{40} \Big/ \dfrac{1}{100} = 25 \text{ miles in 12 hours.} \\ V_y = \dfrac{10}{50} \Big/ \dfrac{1}{80} = 16 \text{ miles in 12 hours.} \end{cases}$

November 15, 8 hours $\begin{cases} V_x = \dfrac{10}{25} \Big/ \dfrac{1}{135} = 54 \text{ miles in 12 hours.} \\ V_y = \dfrac{10}{60} \Big/ \dfrac{1}{150} = 25 \text{ miles in 12 hours.} \end{cases}$

November 16, 8 hours $\begin{cases} V_x = \dfrac{10}{20} \Big/ \dfrac{1}{100} = 50 \text{ miles in 12 hours.} \\ V_y = \dfrac{10}{60} \Big/ \dfrac{1}{120} = 20 \text{ miles in 12 hours.} \end{cases}$

The track given by these values of velocities is given in Fig. 10, which agrees very closely with the track actually observed. The calculated position of the centre is shown by circles and the observed position by crosses.

(*c*) *Depression of July* 24, 1927. (Figs. 24–26.)

For this depression no special observations are available. The isallobars are drawn on the pressure change during the 24 hours (Fig. 24). These give the following values for the velocities of the pressure centre.

$$V_x = 210 \text{ miles in 24 hours.}$$

$$V_y = 25 \text{ miles in 24 hours.}$$

The calculated velocity therefore indicates that on the next morning at 8 hrs. the centre of the depression will be at Pendra whereas it was actually halfway between Jubbulpore and Pendra. The calculation, therefore, gives a smaller velocity than the actual by 25 per cent. This is due to an under-estimate of the tendency values.

It is clear from this example that an elongated depression generally moves very nearly in the direction of the major axis.

Working rules.

From the formulæ and the examples given above, the following working rules relating to cyclones and anticyclones are readily deduced:—

(1) A cyclonic or anticyclonic centre moves normal to the isallobar passing through the centre.

(2) Pressure centres, whose profiles are steep, move slowly.

(3) Flat pressure centres, accompanied by isallobaric gradient of some magnitude, move quickly.

(4) A pressure centre is stationary when the tendency is uniform in all directions.

(5) Very oblong cyclones or anticyclones generally move along the longest symmetry axis.

(6) The deepening celerity of a pressure centre is equal to the barometric tendency in the pressure centre.

BIBLIOGRAPHY.

G. Dedebant—Le champ du déplacement instantané des isobares.—*C.R.A.S.*, t. 185, p. 359, (1927).

G. Dedebant—Contribution mathématique à l'analyse du champ de pression.—*C.R.A.S.*, t. 189, p. 1091, (1929).

G. Dedebant—L'evolution barometrique—Association française pour l'avancement des sciences, La Havre, p. 357, (1929).

M. Mezin—Cinématique des éléments de lignes et de surfaces d'égale cote, appliquée à la météorologie.—*C.R.A.S.*, t. 191, p. 555, (1930).

G. Dedebant—Cinematique des centres isobariques.—*C.R.A.S.*, t. 194, p. 1673, (1932).

G. Dedebant—L' evolution barometrique—*C.R.A.S.*, t. 196, p. 1736, (1933).

G. Dedebant—Les enveloppes d'isobares—*C.R.A.S.*, t. 197, p. 1395, (1933).

S. Petterssen—Kinematical and dynamical properties of the field of pressure with application to weather forecasting. *Geofysiske Publikasjoner*, Vol. X, (1933).

S. Petterssen—Practical rules for prognosticating the movement and the development of pressure centres. *Union Geodesique et Geophysique Internationale, Procès-Verbaux de l'Association de Météorologie, Lisbonne*, (1933).

DISCUSSION.

***President*:** **This paper is now open for discussion. Has this method been used largely in the department?**

Dr. Banerji: Every forecaster uses the laws in a qualitative way. At Bergen this method is being successfully applied daily in a quantitative manner by Prof. Sverre Petterssen who is a member of the Norwegian Meteorological Service. We have tried it on certain days in a very rough way; calculations can be made fairly quickly. This method is easy to apply in Europe where barometric tendencies are regularly reported. In India these tendencies are not reported for day to day work and so the calculation has to be based on changes for past 12 hours or more. This introduces very considerable error. But I think the method is well worth trying.

President: What has been the amount of success in the calculated predictions ?

Dr. Banerji: I do not think we have given a fair trial to the method to say definitely about its success in India. The accuracy of the prediction depends on the accuracy with which the isobaric and isallobaric charts are drawn. From the crude trials we can only say that it gives fairly correctly the direction of movement of a storm as well as changes that are likely to take place in it.

Dr. Roy: Could Dr. Banerji tell us if the kinematical methods of analysis would be helpful in forecasting when a cyclone recurves ?

Dr. Banerji: If the isobars and isallobars are drawn with a reasonable degree of accuracy, an indication of the recurving of a cyclone will be obtained from the components of velocity. The axes are drawn in the directions of maximum and minimum curvatures of the isobars and it will be observed from the examples given that when recurvature occurs the axes undergo a rotation.

Mr. Basu: Dr. Banerji said that although over the sea there is indefiniteness in drawing isobaric lines, over land they can be done with greater accuracy. I would like to know whether uncertainties of measuring distances on maps of the scale that we use, *viz.*, one in ten million or one in fifteen or twenty million, influence the calculations to any appreciable extent. The second point I wish to raise is this. Dr. Banerji has shown that the use of isobaric tendencies for three hours is quite satisfactory in working out Petterssen's equations. But in India we do not have barometric tendencies for 3 hours reported. On the other hand I remember an occasion when Dr. Banerji applied these equations to forecast the track of a cyclone at the head of the Bay of Bengal, by using the 12 hour pressure changes in place of 3 hourly tendencies, and the predicted path was very far out from the actual path, the centre which was forecasted to be over Purnea on the next day being actually near Barisal so that while recommending a trial of these methods in India, he said that it would be better to have barometric tendencies for 3 hours. Could Dr. Banerji indicate whether an interval of more than 3 hours but less than 12 hours will be suitable, and if so what interval ?

Dr. Banerji: In the particular case referred to, changes were calculated on barometric observations taken 24 hours before; Poona had no evening chart then. With the data available the acceleration terms could not be calculated,

The example cannot be considered to be a fair trial of the method. It is necessary to realize that both the velocity and acceleration terms are important, for although the value of the acceleration is small compared with the velocity, it is multiplied by the square of the time. As for the scale of the map, I do not think that the scale we now use introduces any large error in the calculation. As regards the second point, too small an interval, like an hour, is not good for the reason that there is a limit of accuracy to which barometers can be read and so the changes recorded over small intervals of time will be considerably in error. In many cases the change will be of the same order as the error in determining it. On the other hand, if the interval is too large, 12 hours or 24 hours, we cannot obviously use the quantities in getting accurate values of differential coefficients. The mathematical formulæ are accurate; the difficulty is in getting correct numerical values.

President: The mathematics is always accurate; the fault is only of the observations. I now request Dr. Normand to give a short review of the discussion. It is for the President to have done that, but meteorology is strange to me and I hope that Dr. Normand will come to our help.

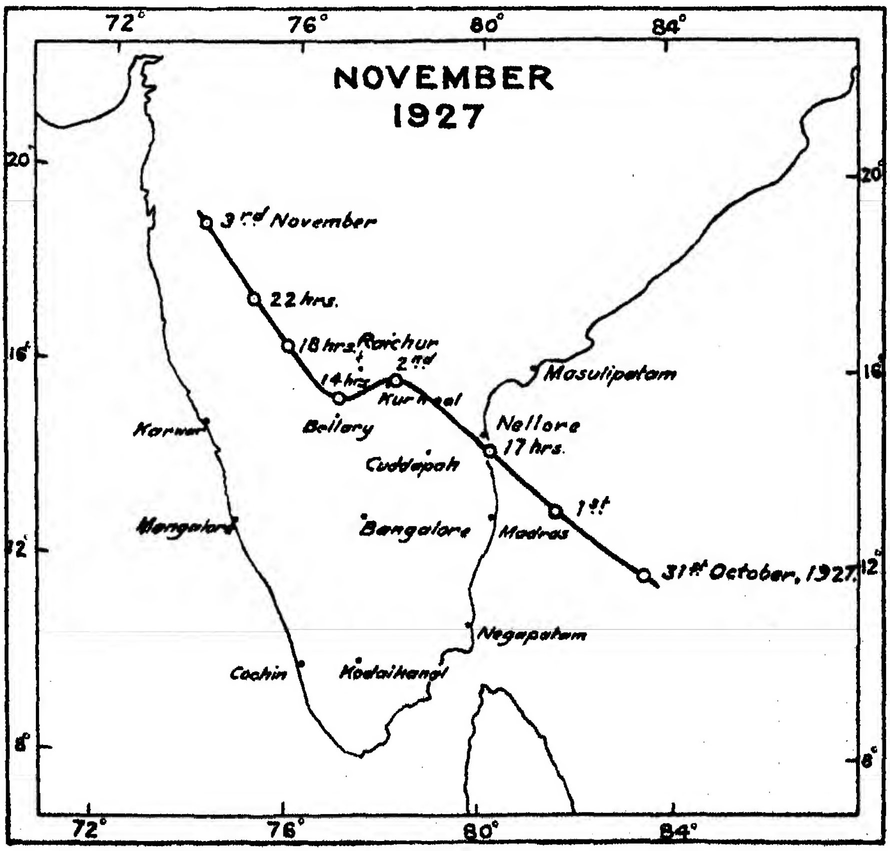


FIG. 2.

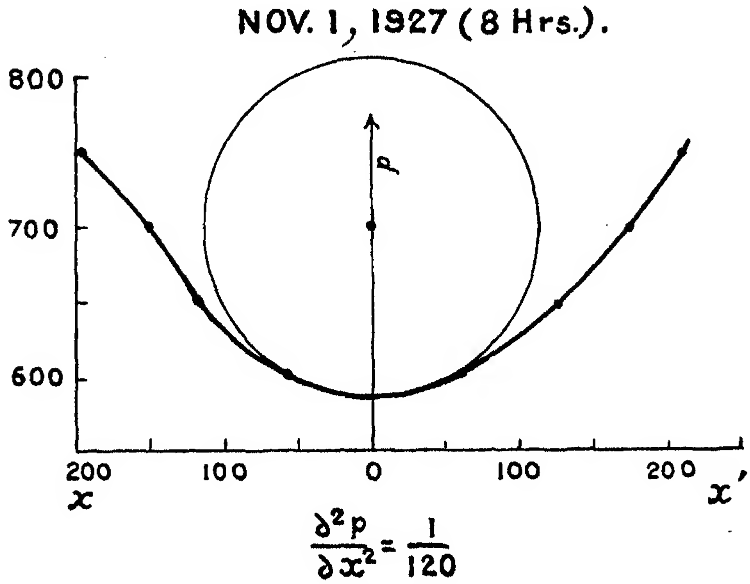

NOV. 1, 1927 (8 Hrs.).
800
700
600
p
200
100
0
100
200
x
x'
$\frac{\partial^2 p}{\partial x^2} = \frac{1}{120}$

FIG. 3.

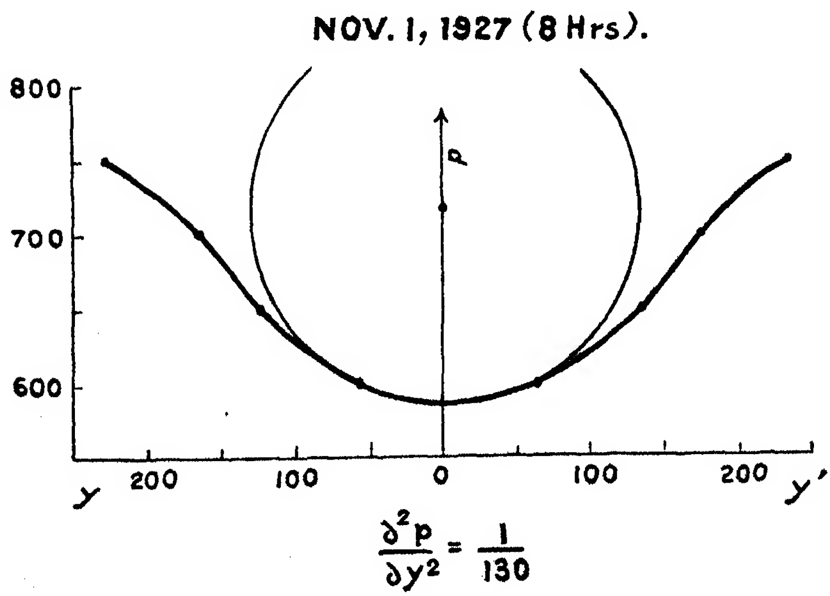

NOV. 1, 1927 (8 Hrs).
800
700
600
p
200
100
0
100
200
y
y'
$\frac{\partial^2 p}{\partial y^2} = \frac{1}{130}$

FIG. 4.

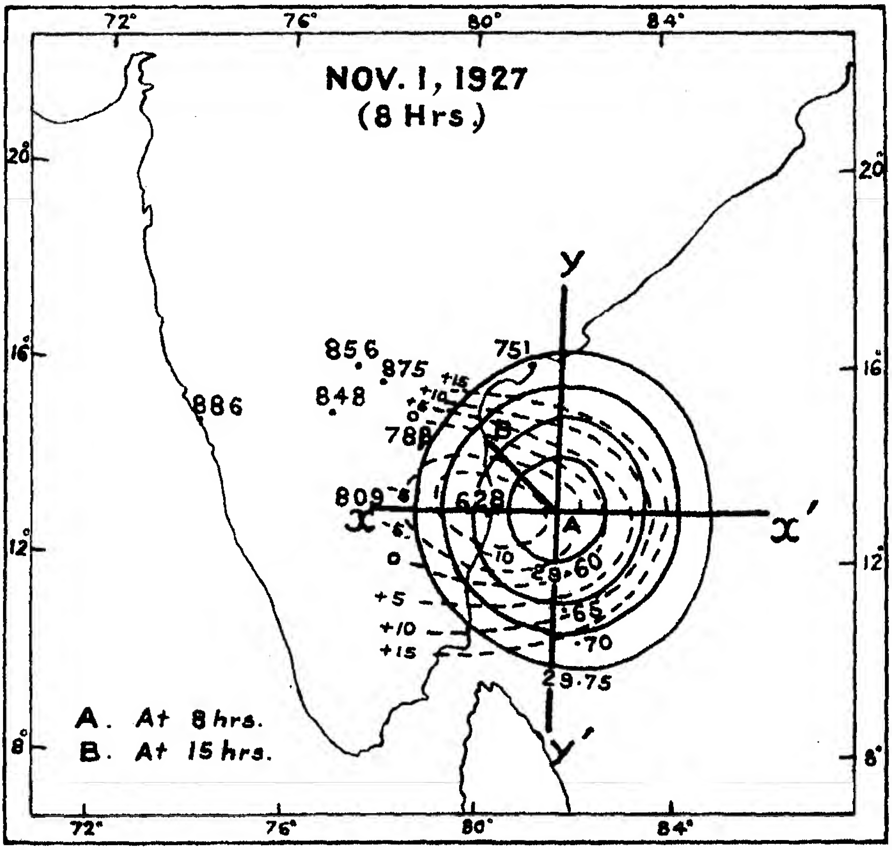

NOV. 1, 1927
(8 Hrs.)
72°
76°
80°
84°
20°
16°
12°
8°
886
856
875
848
751
788
809
628
29.60
·65
·70
29.75
A
B
x
x′
y
y′
+15
+10
+5
0
-5
-10
A. At 8 hrs.
B. At 15 hrs.

Fig. 5.

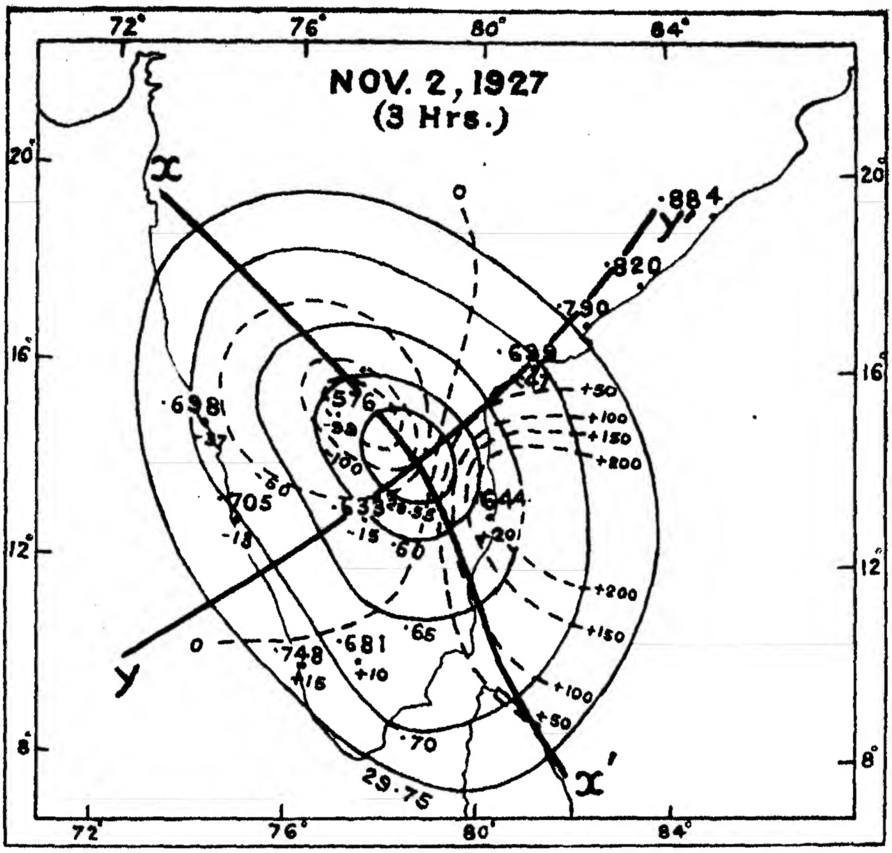

NOV. 2, 1927
(3 Hrs.)
72°
76°
80°
84°
20°
16°
12°
8°
x
x'
y
y'
·884
·820
·790
·639
·698
·576
·705
·533
·644
·748
·681
·65
·70
29·75
+50
+100
+150
+200
+20
+10
+15
-15
-60
-50
-100
0

Fig. 6.

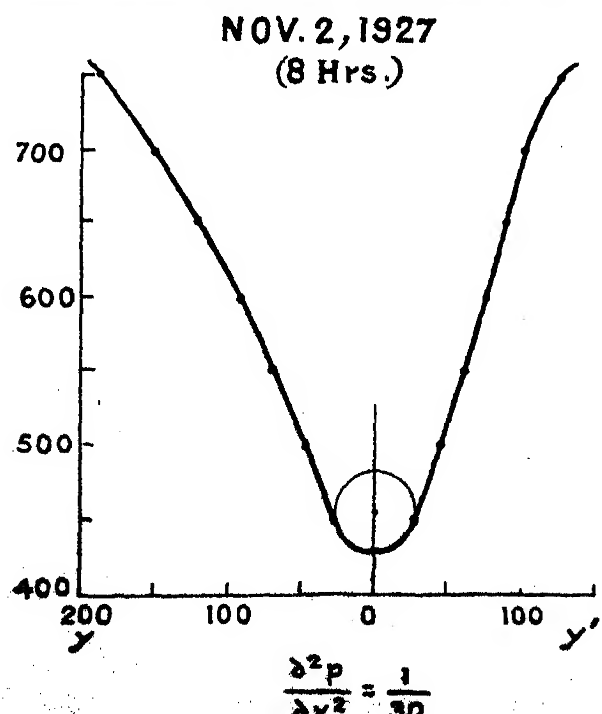
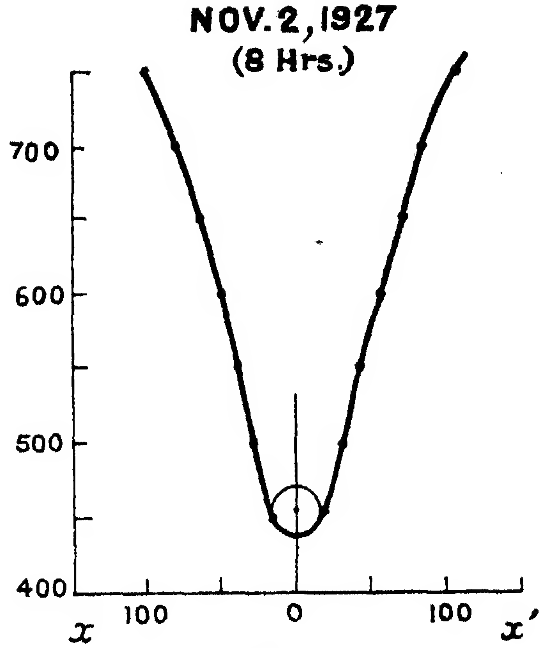

NOV. 2, 1927
(8 Hrs.)
700
600
500
400
200
100
0
100
y
y'
$\frac{\partial^2 p}{\partial y^2} = \frac{1}{30}$

Fig. 7.



$$\frac{\partial^2 p}{\partial x^2} = \frac{1}{17}$$

FIG. 8.

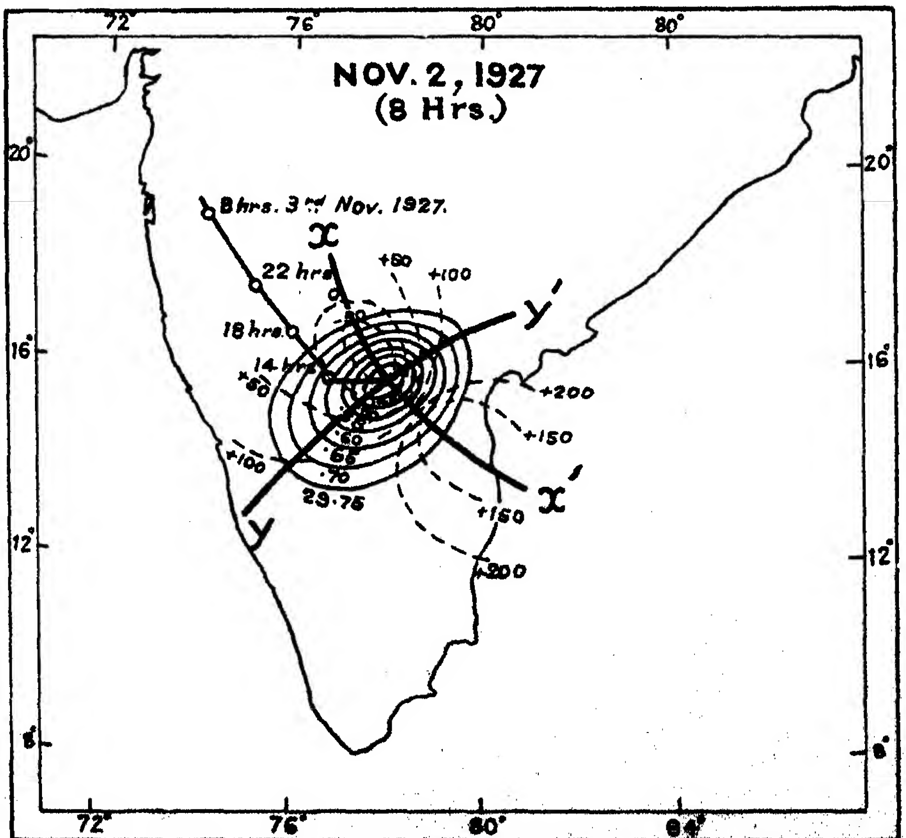


FIG. 9.

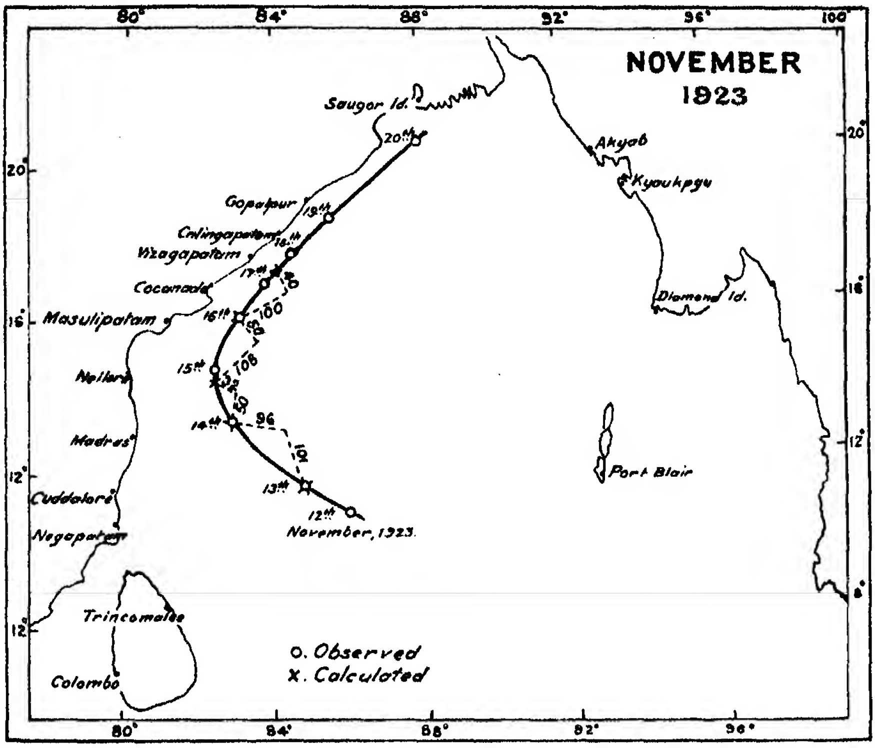

NOVEMBER
1923
Saugor Id.
Akyab
Kyoukpyu
Gopalpur
Calingapatam
Vizagapatam
Cocanada
Masulipatam
Nellore
Madras
Cuddalore
Negapatam
Trincomalee
Colombo
Diamond Id.
Port Blair
November, 1923.
o. Observed
x. Calculated

FIG. 10.

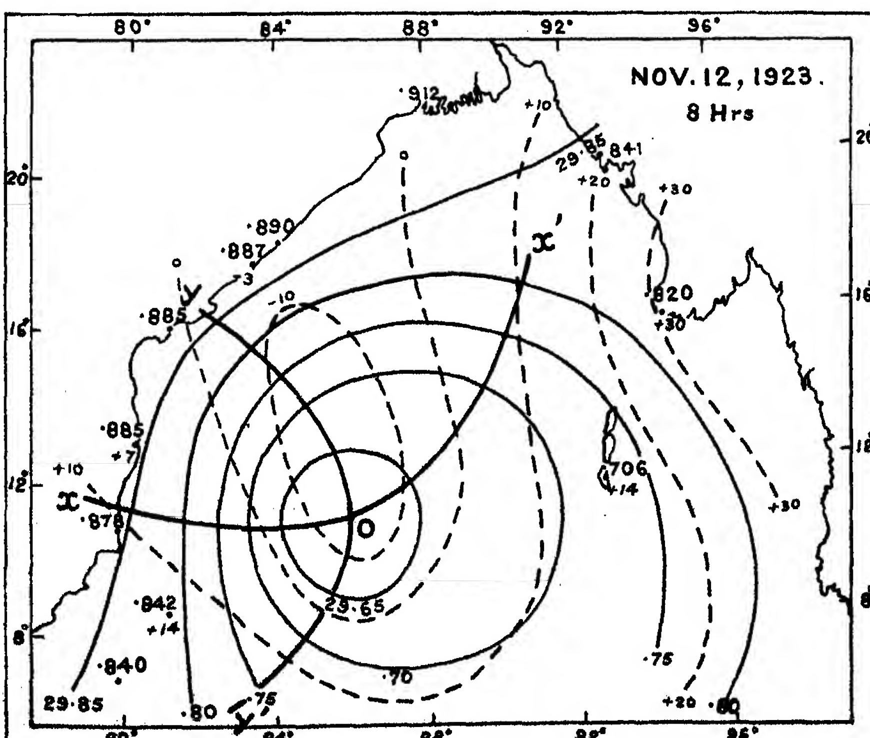

NOV. 12, 1923.
8 Hrs
29·85
29·65
·70
·75
·80

FIG. 11.

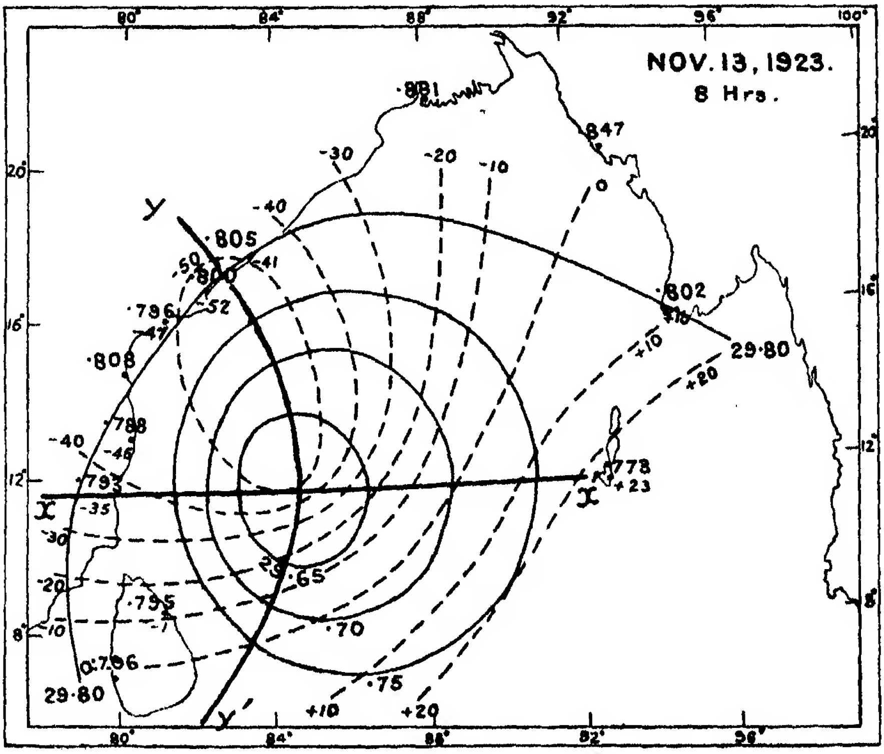
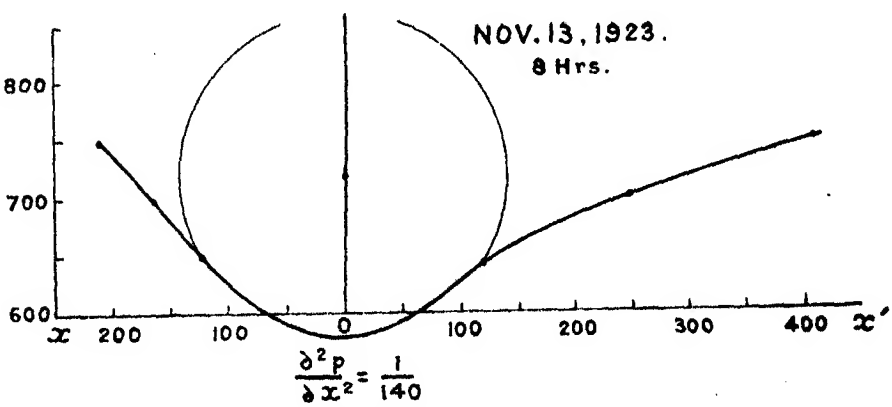
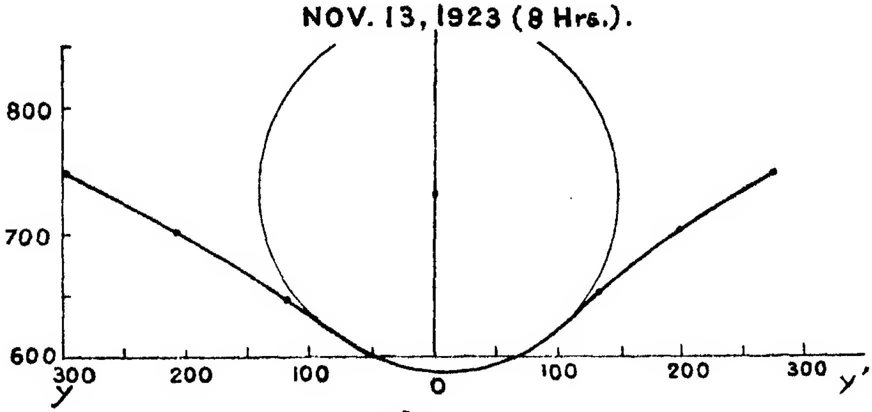


FIG. 12.



$$\frac{\partial^2 p}{\partial x^2} = \frac{1}{140}$$

FIG. 13.



$$\frac{\partial^2 p}{\partial y^2} = \frac{1}{150}$$

FIG. 14.

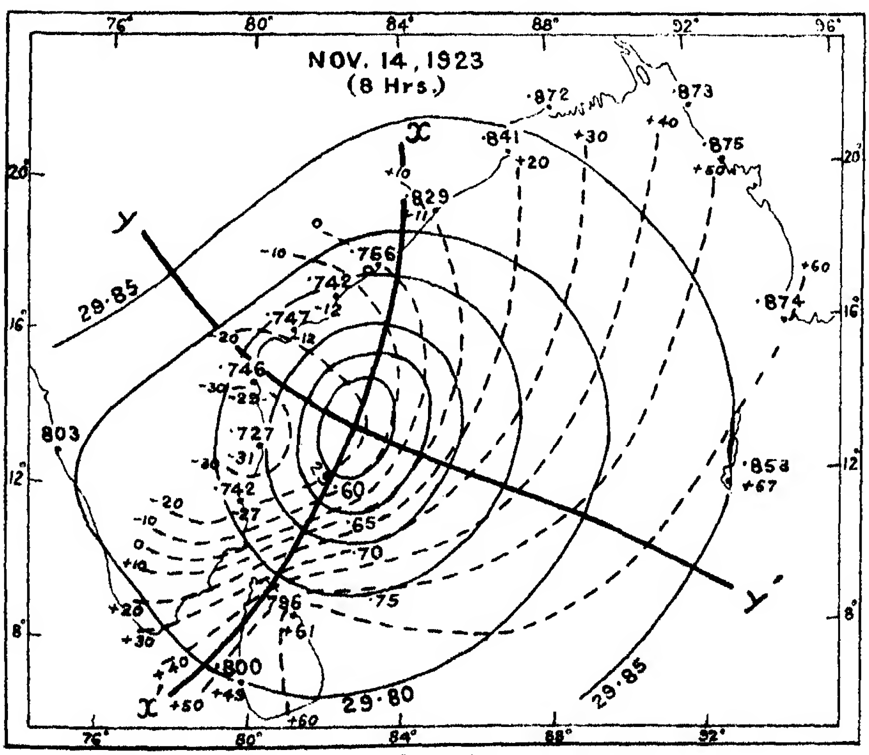


FIG. 15.

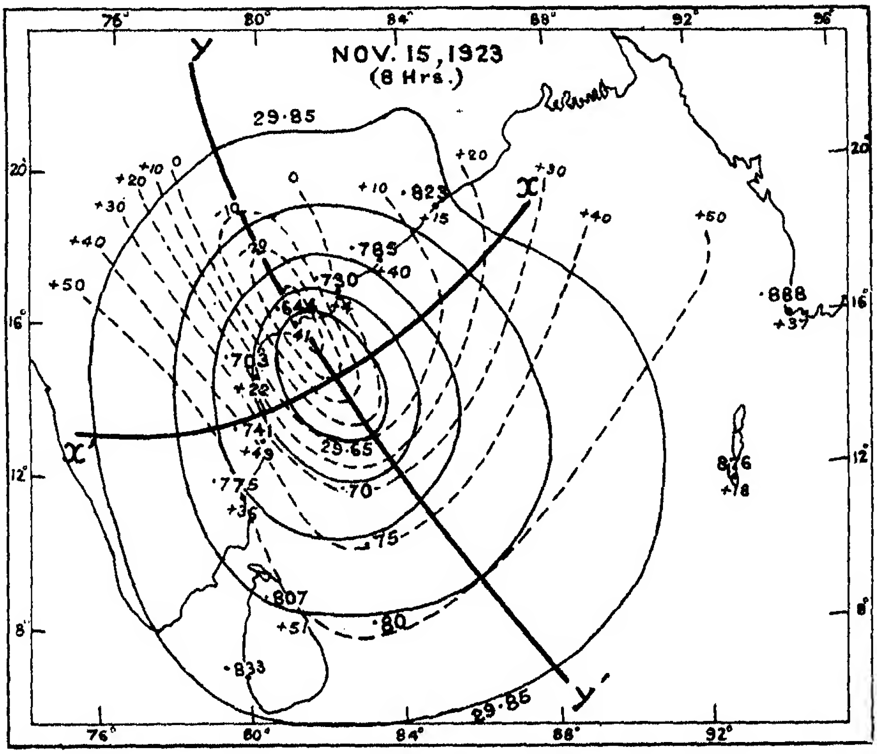

NOV. 15, 1923
(8 Hrs.)
29·85
29·65
·70
·75
·80
·823
·785
·730
·703
·741
·775
·807
·833
·888
+37
76°
80°
84°
88°
92°
96°
20°
16°
12°
8°

FIG. 16.

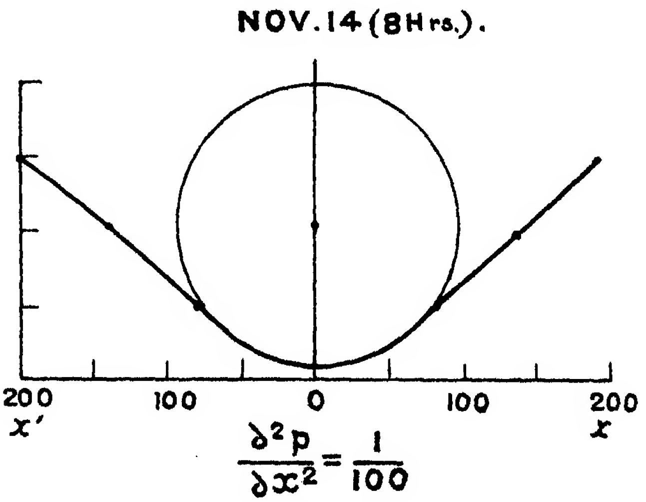

NOV. 14 (8 Hrs.).
200
100
0
100
200
x'
x
$\frac{\partial^2 p}{\partial x^2} = \frac{1}{100}$

FIG. 17.

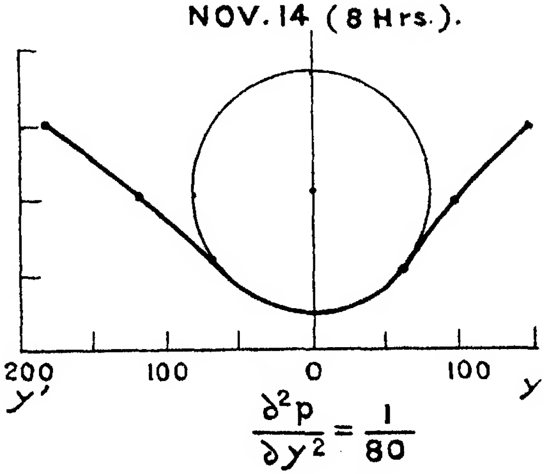

NOV. 14 (8 Hrs.).
200
100
0
100
y'
y
$\frac{\partial^2 p}{\partial y^2} = \frac{1}{80}$

FIG. 18.

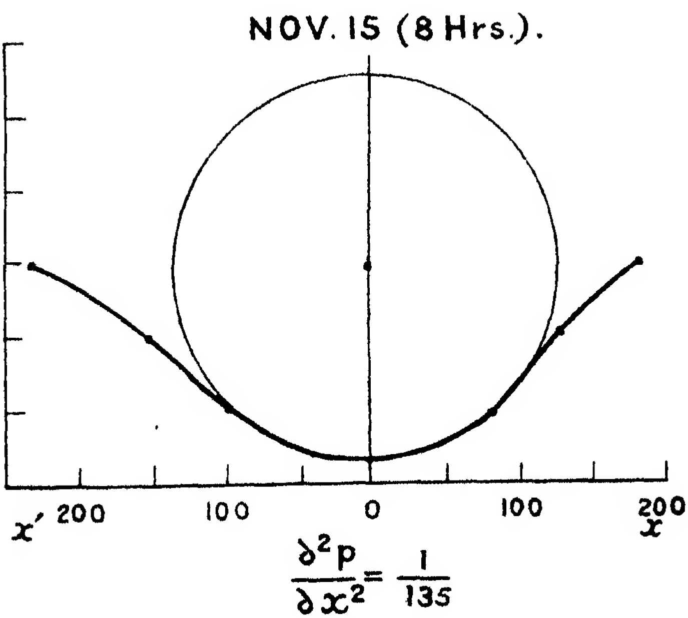
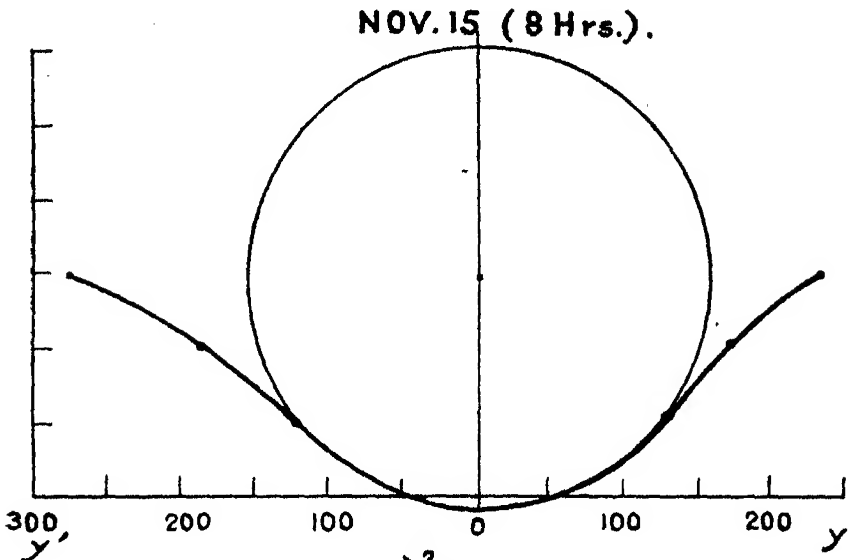

NOV. 15 (8 Hrs.).
x'
200
100
0
100
200
x
$\frac{\partial^2 p}{\partial x^2} = \frac{1}{135}$

FIG. 19.



$$\frac{\partial^2 p}{\partial y^2} = \frac{1}{150}$$

FIG. 20.

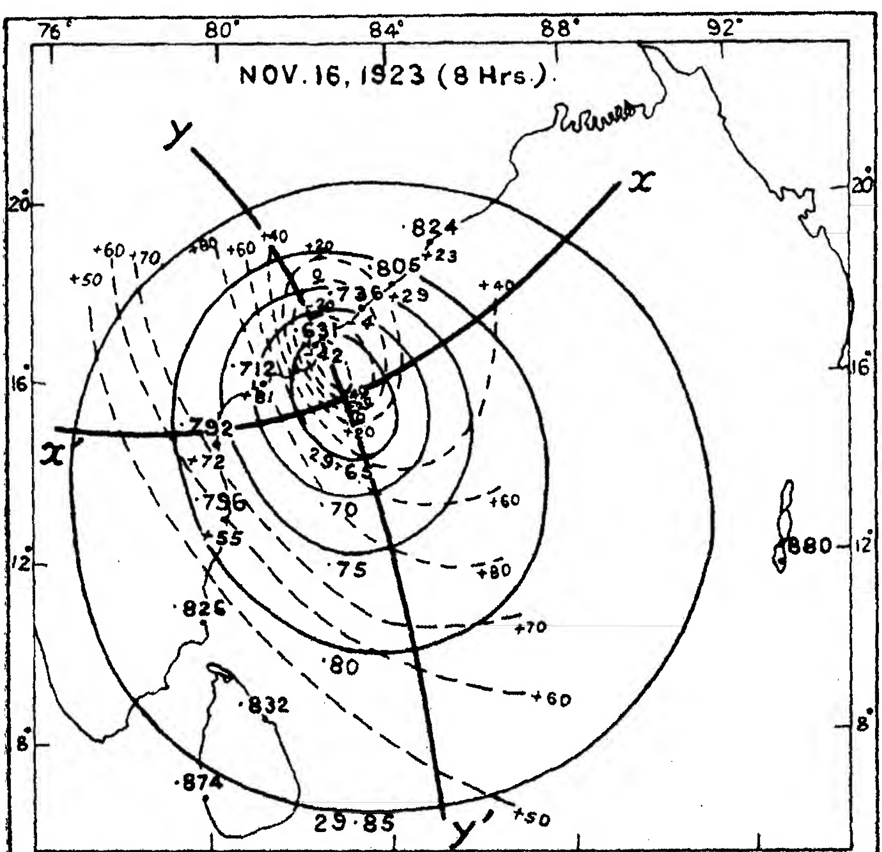


FIG. 21.

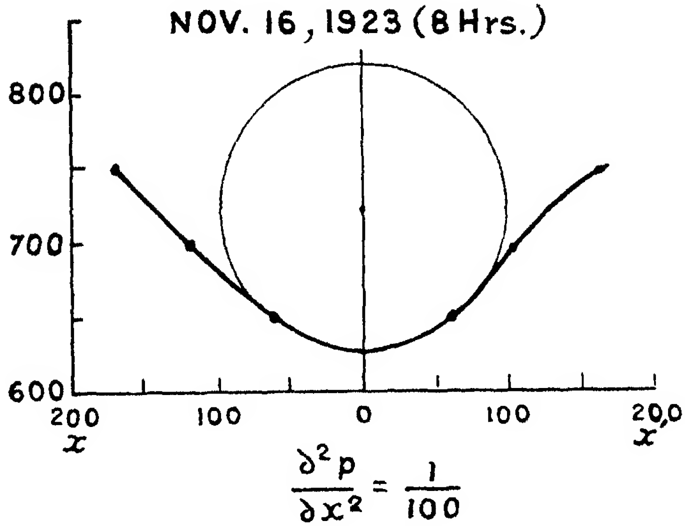

NOV. 16, 1923 (8 Hrs.)
800
700
600
200
100
0
100
200
x
x
$\frac{\partial^2 p}{\partial x^2} = \frac{1}{100}$

FIG. 22.

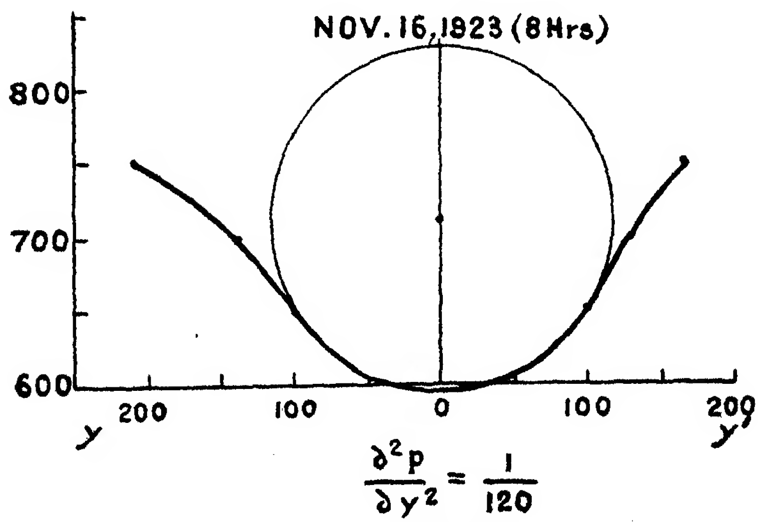

NOV. 16, 1923 (8 Hrs)
800
700
600
200
100
0
100
200
y
y
$\frac{\partial^2 p}{\partial y^2} = \frac{1}{120}$

FIG. 23.

REFLECTION AND ABSORPTION OF THE ELECTROMAGNETIC WAVES IN THE IONOSPHERE.

By K. B. MATHUR, *M.Sc., Physics Department, University of Allahabad.*

(Communicated by Prof. M. N. Saha, F.R.S., F.N.I.)

(*Read April 5, 1939.*)

The problem of total reflection of e.m. waves from the Ionosphere has been studied by numerous investigators. Appleton (1932), who is the pioneer worker in this field, assumes that when collisional damping can be neglected, for vertical incidence reflection takes place, when the refractive index becomes equal to zero. From this assumption he obtained three conditions of reflections now well known. Following the discovery of Pant and Bajpai (1937) of a case of reflection in which $f_0-f_x=\cdot 14$ Mc./sec. instead of $\cdot 64$ Mc./sec. for 4 Mc./sec., Rai (1937) showed that the observation can be explained if it is supposed that reflection takes place when group velocity becomes equal to zero. He showed that this assumption leads to Appleton's condition, plus a fourth one, which amounts to taking refractive index $=\infty$. This explained the results giving $f_0-f_x=\cdot 14$ Mc./sec. Bajpai (1937) arrived at the same result from the assumption that reflection takes place when the variation of refractive index with the number of electrons becomes very large. But none of the above mentioned authors tried to find the conditions of reflection when the collisions of electrons are taken into account. Recently Bose (1938) has tried to solve this problem. He thinks that reflection takes place either when H, the magnetic vector of the wave, becomes zero or E, the electric vector, becomes parallel to the direction of propagation of the wave. His line of argument is that when both the above-mentioned conditions hold the disturbance loses its wave character and hence should get reflected. But it has been found that when these conditions are fully expanded they reduce to the conditions, either the refractive index should be put equal to zero or to infinity. R. C. Majumdar (1938) has also attempted this problem. He thinks that reflection takes place when the Poynting vector is perpendicular to the direction of propagation. Ultimately his conditions also reduce to refractive index equal to zero and infinity. But in case where collision cannot be neglected the refractive index becomes complex and algebraically it cannot be put equal to zero unless the real part as well as the imaginary part are separately put equal to zero. It can, however, be easily shown that this leads to an absurd result. What is the condition of reflection in such cases? Before taking up this case, let us see how the refractive index varies in some simple

cases with height. We can put the complex refractive index q as $q = \mu + \frac{ick}{p}$. Mary Taylor (1934), Goubau (1935), Martyn (1935) and others have drawn numbers of curves showing variation of μ, k with the electron density, for a particular value of frequency and different values of collisional frequency. From these it is clear that at certain values of electron concentration μ assumes very small values, but never becomes zero, or negative. The same is the case with absorption coefficient. But it should be emphasized that the refractive index curves drawn by these authors give one no idea of the actual variation of μ with height because they plot a series of (μ, z) curves with fixed values of collision frequency, while μ is a function of N (the number of electrons) and ν (the collision frequency), both of which are functions of height. What we want to know is the actual variation of μ and k with height. For this purpose, the best course would be to draw such curves by assuming certain variation of N and ν with height.

In this paper, such curves have been drawn for a so-called simple layer. It is very probable that in the case of actual stable layers (like the E and F) a simple layer represents the actual variation of electron density with height, because Saha and Rai (1938) have actually shown that even continuous radiation which produces ionization of a definite constituent produces the same kind of layer as a simple layer. This was formerly supposed to rise from monochromatic radiation alone, and hence it was open to doubt whether a simple layer could actually represent a stable layer like the E or the F-region.

§ 1.

We have the Appleton Hartree formula (Bajpai and Mathur, 1939)

$$C'q^2 = (r-\beta)(\omega^2-\beta^2+r\beta) - \frac{r\omega^2}{2}\sin^2\alpha\left[1 \pm \sqrt{1+\frac{4(r-\beta)^2\cos^2\alpha}{\omega^2\sin^4\alpha}}\right] \quad \ldots \quad (1)$$

where

$$C' = \beta(\beta^2-\omega^2) - r(\beta^2-\omega^2\cos^2\alpha)$$

$$r = \frac{4\pi Ne^2}{mp^2} = \frac{p_0^2}{p^2}$$

α = angle of dip.

$$\beta = 1 - i\delta$$

$$\delta = \frac{\nu}{p}$$

$$\omega = \frac{eh}{mcp} = \frac{p_h}{p} \text{ with components } \omega_x, \omega_y, \omega_z$$

p_x, p_y, p_z = components of Larmor frequency p_h

p = pulsatance of the wave

N = the number of electrons

ν = collisional frequency

h = earth's magnetic field

q = complex refractive index

$$= \mu + i\frac{ck}{p}$$

k = absorption coefficient

μ = real part of refractive index.

Suffixes o and e will be used to denote the constants for the ordinary and the extra-ordinary waves respectively. For the quasi-transverse case, i.e., when

$$\frac{4(r-\beta)^2 \cos^2 \alpha}{\omega^2 \sin^4 \alpha} < 1$$

equation (1) reduces to

$$q_0^2 = 1 - \frac{r}{\beta} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

for the ordinary O-wave—i.e., when we take negative sign in (1) into consideration.

From (2) we have

$$\left.\begin{aligned} \mu_0^2 &= \frac{1}{2}\left[\sqrt{X^2+Y^2}+X\right] \\ \frac{c^2k_0^2}{p^2} &= \frac{1}{2}\left[\sqrt{X^2+Y^2}-X\right] \end{aligned}\right\} \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

where

$$X = 1 - \frac{r}{1+\delta^2}, \quad Y = \frac{r\delta}{1+\delta^2} \quad \ldots \quad \ldots \quad \ldots \quad (3')$$

The algebraic expressions (3) show at a glance that neither μ_0^2, nor k_0^2 can ever be negative even when X is negative. Generally for X positive, μ_0^2 is large, and k_0^2 is small, but when X is negative, μ_0^2 is small but k_0^2 is large.

Assuming the variation of N with height as given by Chapman's formula (1931) we have

$$r = \frac{4\pi Ne^2}{mp^2} = \frac{4\pi N_0 e^2}{mp^2} \cdot \epsilon^{\frac{1-z'-\epsilon^{-z'}\sec\chi}{2}} \quad \ldots \quad \ldots \quad (4)$$

where

$$z' = \frac{z-z_0}{H}$$

$$H = \frac{kT}{mg}$$

k = Boltzmann's constant

T = absolute temperature

m = mean molecular mass

g = acceleration due to gravity

z_0 = height of maximum ionization at the equator at equinox

N_0 = electron concentration at the maximum of ion production

χ = angle of incidence of the ionizing radiation from the zenith.

The variation of collisional damping with height is assumed to be given by

$$\delta = \frac{\nu}{p} = \frac{\nu_0}{p} \epsilon^{-z'} \quad .. \quad .. \quad .. \quad .. \quad (5)$$

In (4) the value of N_0 is taken equal to $1{\cdot}5 \times 10^5$, and in (5) the value of ν_0 is taken as 10^5, which are valid in the case of E-region.

With the help of (3), (3′), (4) and (5) curves for the ordinary wave have been drawn for $X = 0$ between μ_0, z' and k_0, z' for different frequencies.

Remarks about the curves.

Fig. (1) shows a curve for $p = 1{\cdot}4141 \times 10^7$ ($\lambda = 133{\cdot}2$ m.) and is representative for frequencies smaller than the penetration frequency. The μ_0 and k_0 curves are indicated by the continuous and broken lines respectively. The form of these curves show that the so-called deviating region begins from nearly $z' = -2{\cdot}5$, i.e. at a depth of about 25 kms. below the maximum concentration level (if H is taken equal to 10 km.). For the layer $z' = -1{\cdot}4$ to $z' = +2{\cdot}6$, i.e. a distance of 40 kms. μ_0 is extremely small. Assuming that the reflection takes place where change of μ_0 with z' is very large, the wave train will get reflected from the point A_0 and probably from B_0. For the vacuum wavelength $\lambda = 133{\cdot}2$ m. the actual wavelength in the region where μ_0 is very small (taking mean value of μ_0 as ·004) is 33·3 kms., which is of the same order as the electron barrier and hence there is every possibility of the wave leaking through. But due to high absorption in this region

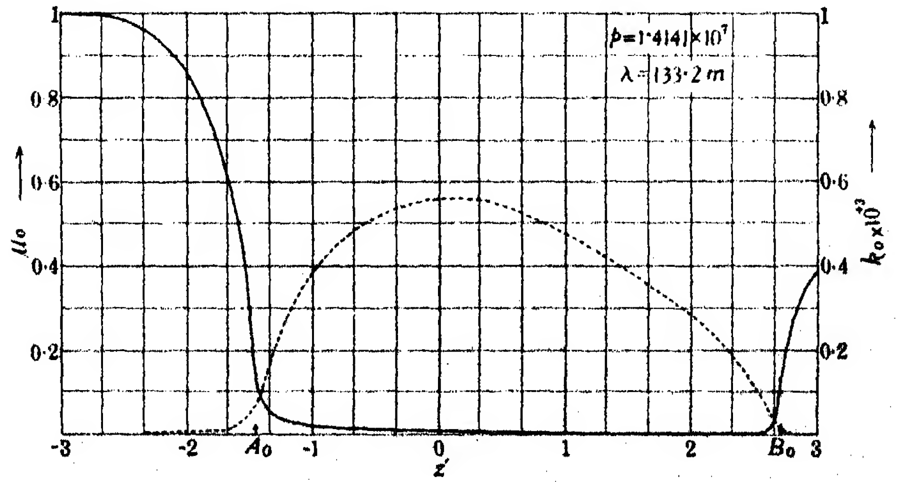


FIG. 1.

probably the disturbance is completely absorbed before it reaches B_0. In the $\mu_0 - z'$ curve the minimum value is reached at $z' = +2{\cdot}5$.

For the region where μ_0 is very small k_0 continues to be great. It has its maximum at $z' = 0$. The total integrated absorption coefficient $\kappa = (2\int kds)$ can be easily calculated from the k-curve. For the wave reflected from A_0, κ is given by twice the area bounded by the k-curve, the abscissa and on the left of a vertical line passing through A_0. $\kappa = 14{\cdot}66$ for reflection from A_0

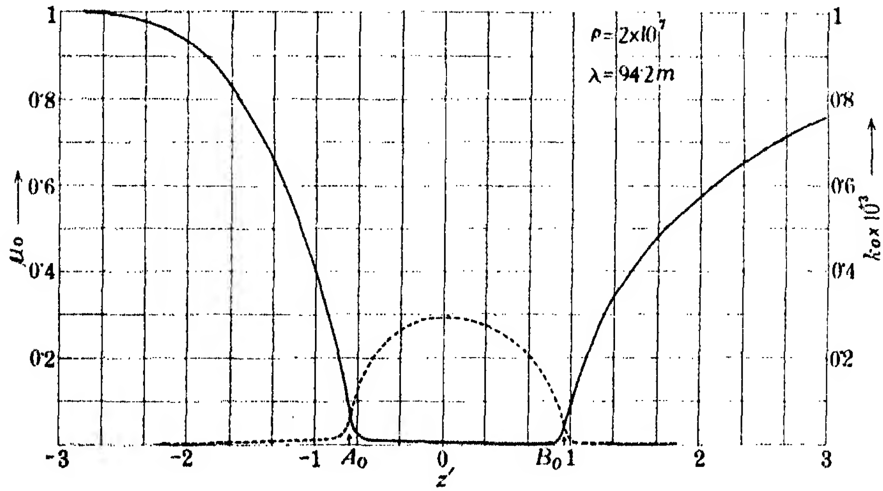


FIG. 2.

and $\kappa = 3282$ for reflection from B_0, which shows that there is no possibility of reflection from B_0.

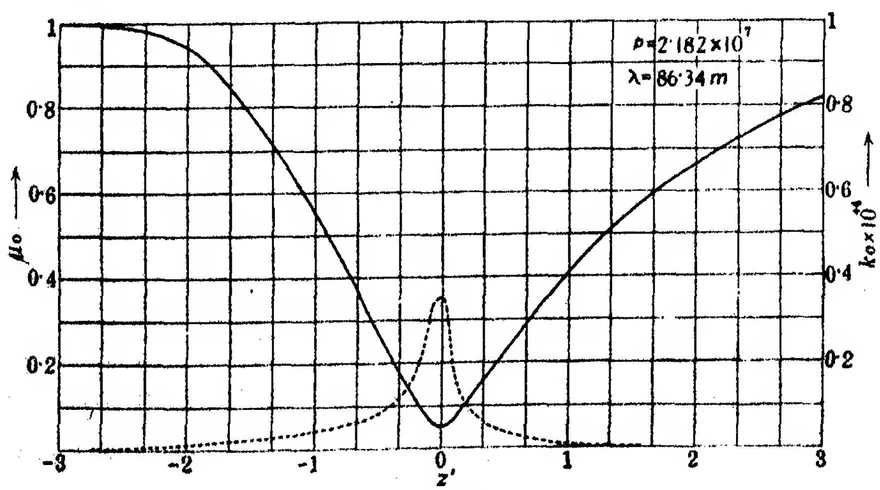


FIG. 3.

In fig. (2) $\mu_0 - z'$ and $k_0 - z'$ curves are drawn for $p = 2 \times 10^7$ ($\lambda = 94{\cdot}2$ m). It belongs to the same group as the curve in fig. (1). Here the flat portion of the μ_0-curve as well as the maximum of k_0-curve have decreased. κ for the wave reflected from A_0 is 16, while for that reflected from B_0 it is 780.

In fig. (3) $\mu_0 - z'$ and $k_0 - z'$ curves are drawn for frequency equal to the penetration frequency which is $p = 2{\cdot}182 \times 10^7 = p_c$ ($\lambda = 86{\cdot}34$ m.). Here the flat portion which is so prominent in figs. (1) and (2) has disappeared. The two branches of the curves meet at $z' = 0$. It is quite clear that absorption is also maximum at $z' = 0$. The minimum value of μ_0 is 0·05, while the maximum value of k_0 is one-tenth of that in fig. (2). Evidently the nature of the curve shows that there is no reflection at $z' = 0$, because μ_0 is changing gradually and the change of μ_0 with z' is not large. κ due to this region will be given by twice the area bounded by the k-curve and the abscissa and is nearly 39·6.

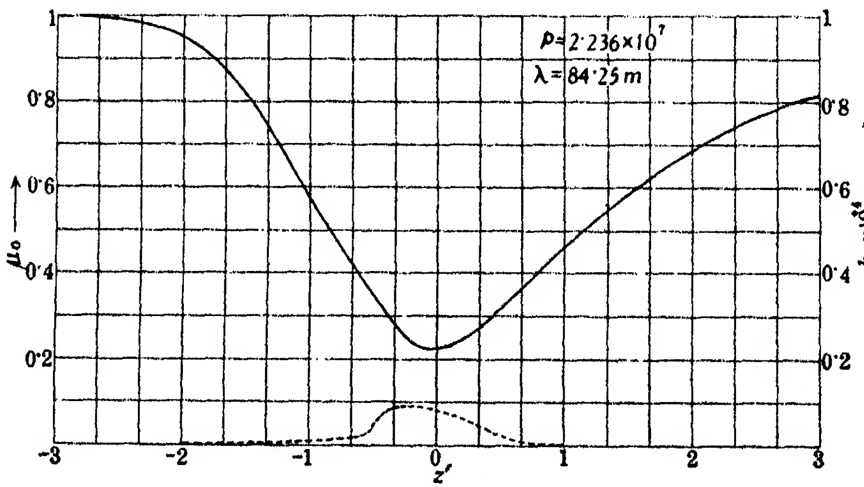


FIG. 4.

Fig. (4) shows μ_0, k_0-curves for $p = 2{\cdot}24 \times 10^7$ ($\lambda = 84{\cdot}3$ m.) which is greater than p_c. The form of the curve is similar to that in fig. (3), but the minimum value of μ_0 is now only 0·22, while the maximum value of k_0 is also much reduced. In this case κ is nearly 15·5.

Fig. (5) shows μ_0, k_0-curves for $p = 4 \times 10^7$ ($\lambda = 47{\cdot}2$ m.). Here the minimum value of μ_0 is only 0·84, while absorption is practically negligible. The total integrated absorption coefficient κ is 4·90. The maximum value of k_0 is attained at $z' = -1{\cdot}1$, as is expected from theory (Appleton, 1938) if the layer behaves as a non-deviating region for this frequency.

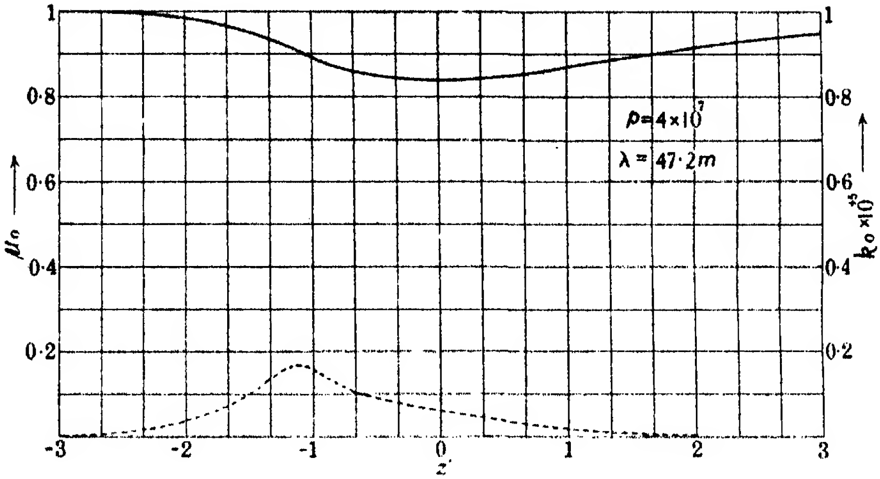


FIG. 5.

§ 2.

For the extra-ordinary wave in the quasi-transverse case (when we take + sign) we have from (1)

$$q_e^2 = 1 - \cfrac{r}{\beta - \cfrac{\omega_x^2}{\beta - r}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

From (6) we have

$$\left.\begin{aligned} \mu_e^2 &= \frac{1}{2}\,[\sqrt{X_1^2+Y_1^2}+X_1] \\ \frac{c^2k_e^2}{p^2} &= \frac{1}{2}\,[\sqrt{X_1^2+Y_1^2}-X_1] \end{aligned}\right\} \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

where

$$\left.\begin{aligned} X_1 &= 1 - \frac{R}{1+D^2}, \qquad & Y_1 &= \frac{RD}{1+D^2} \\ R &= \frac{r}{1+\dfrac{\omega_x^2(r-1)}{(r-1)^2+\delta^2}}, \qquad & D &= \delta\,\frac{1+\dfrac{\omega_x^2}{(r-1)^2+\delta^2}}{1+\dfrac{\omega_x^2(r-1)}{(r-1)^2+\delta^2}} \end{aligned}\right\} \quad \ldots \quad (7')$$

Thus we see that equations (7) are of the same form as equations (3), hence the remarks made on equations (3) hold here too.

Using equations (4), (5) and (7) curves have been drawn for $\mu_e - z'$ and $k_e - z'$ for different frequencies assuming $\chi = 0$ and $p_x = 5\times10^6$.

Fig. (6) is drawn for $p = 1{\cdot}4141\times10^7$ ($\lambda = 133{\cdot}2$ m.). There are two maxima for μ_e : (1) a steep maximum ($\mu_e = 1{\cdot}423$) at $z' = 1{\cdot}5$ and another ($\mu_e = 1{\cdot}379$) at $z' = +2{\cdot}8$. μ_e remains very small between $z' = -1$ to $z' = +2$. There are two more levels, viz. $z' = -1{\cdot}6$ and $z' = +3{\cdot}4$ where

μ_e has minimum values. k_e has its maxima at $z' = -1{\cdot}5$, $z' = 0$ and $z' = +3$. The maximum at $z' = +3$ is the largest while at $z' = 0$ it is very flat.

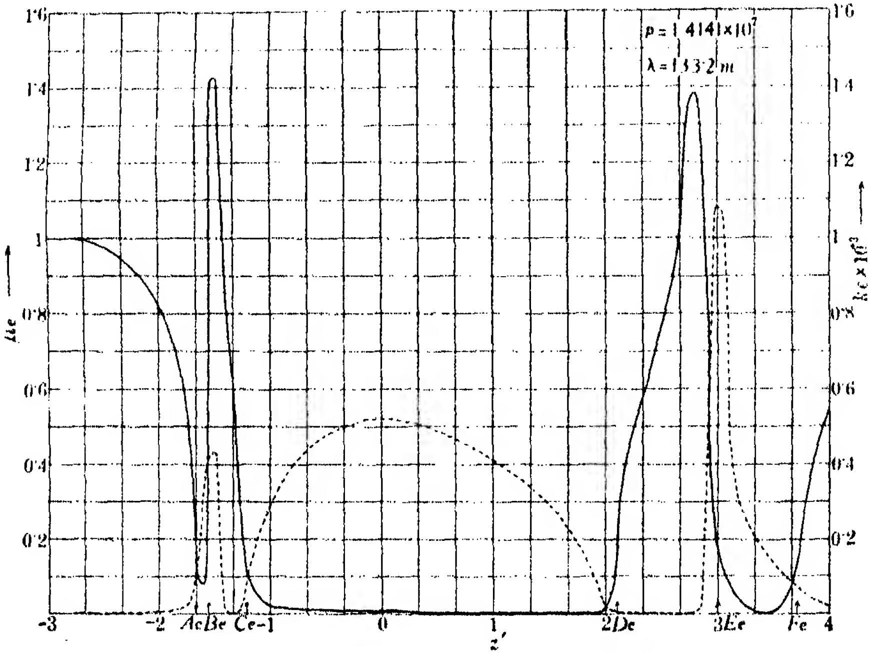


FIG. 6.

Assuming as before that the reflection takes place where the change of μ_e with height is very large, the reflection will take place from A_e, B_e and C_e corresponding to the conditions

$$p_0^2 = p^2 - pp_h \qquad \ldots \quad (\alpha)$$

$$p_0^2 = p^2 \frac{p^2 - p_h^2}{p^2 - p_x^2} \qquad \ldots \quad (\beta)$$

$$p_0^2 = p^2 + pp_h \qquad \ldots \quad (\gamma)$$

respectively, which holds good when $\nu = 0$. The distance between A_e and B_e is nearly 1·3 kms. and since the actual wavelength in the medium is nearly 1·35 kms., i.e. of the same order as the barrier, there is every possibility of the wave leaking through and getting reflected from B_e. We can also deduce from the k_e-curve the total integrated absorption coefficient κ. For the wave reflected from B_e it is 68, which means that the wave will be highly absorbed and hence the probability of its being reflected is very much reduced. Even in exceptionally favourable conditions, if the absorption is small, the equivalent path difference between reflections from A_e and B_e being only

2·6 kms., these reflections will not be resolved at the receiver. The distance between B_e and C_e is nearly 4 kms. and the value of μ_e is sufficiently high, so the actual wavelength in the medium is very very small in comparison to the distance. Hence there is no possibility of the wave leakage. Therefore we cannot get reflections from the point C_e. When the wave cannot be reflected even from the point C_e, there is no possibility of its being reflected from the points D_e, E_e and F_e at all.

The total integrated absorption coefficient κ for the wave reflected from A_e is nearly 12.

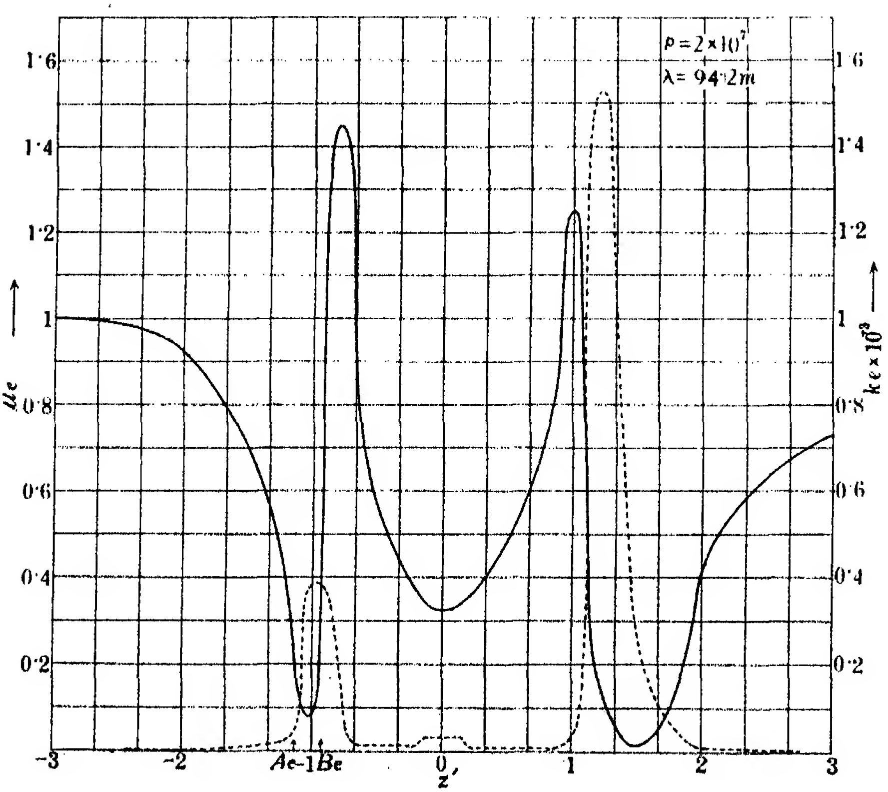


FIG. 7.

In Fig. (7) $\mu_e - z'$ and $k_e - z'$ curves are drawn for $p = 2 \times 10^7$ ($\lambda = 94{\cdot}2$ m). The curves are representative for frequencies for which the conditions of reflection (α) and (β) hold but not (γ). κ for the wave reflected from A_e is 14, while for that reflected from B_e it is 125·6. For reflections from A_e and B_e remarks similar to those made in the preceding paragraph hold good. In figs. (8) and (9) $\mu_e - z'$ and $k_e - z'$ curves are drawn for $p = 2{\cdot}182 \times 10^7$ ($\lambda = 86{\cdot}34$ m.) and $p = 2{\cdot}236 \times 10^7$ ($\lambda = 84{\cdot}25$ m.) respectively. These

frequencies belong to the same group as the one drawn in fig. (7). In fig. (8) the minimum value of μ_e at $z' = 0$ has risen to 1, while in fig. (9) there is no

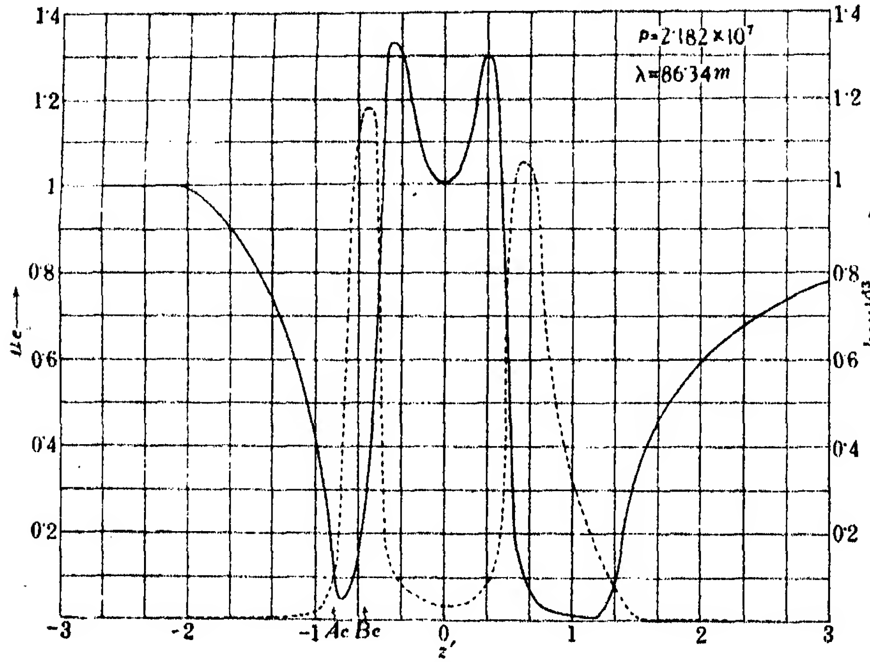


FIG. 8.

minimum, rather the two maxima have shifted to $z' = 0$, and the value of μ_e is 2·395. The curves for frequencies higher than $2{\cdot}236\times10^7$ (not given here) show a gradual fall in the maximum value of μ_e at $z' = 0$, with a corresponding narrowing of the central portion, till the penetration frequency given by the condition (α) is reached, when the curve reduces to that shown in fig. (10). κ for the wave reflected from A_e in fig. (8) is 18, while in fig. (9) it is 20. For the wave reflected from B_e, κ is 397 in fig. (8), while it is 1012·6 in fig. (9). In these curves also, though the distance between A_e and B_e is of the same order as the actual wavelength in the medium, the value of κ is so great that reflection from B_e is not possible.

The value of κ due to this region for the penetration frequency $p = 2{\cdot}4407\times10^7$ ($\lambda = 77{\cdot}02$ m.) for which curves are drawn in fig. (10) is 84. These curves are similar to those in fig. (3) for the ordinary ray. In fig. (11) $\mu_e - z'$ and $k_e - z'$ curves are drawn for $p = 4\times10^7$ ($\lambda = 47{\cdot}2$ m.) representing curves for the frequencies sufficiently greater than the penetration frequency. In this the minimum value of μ_e attained is only ·834 at $z' = 0$ and hence the layer for this frequency behaves as a non-deviating region. But the maximum value of k_e is attained at $z' = -0{\cdot}2$ and not at $z' = -1{\cdot}1$ as was

the case in the ordinary wave of the same frequency as shown in fig. (5). The total integrated absorption coefficient is 1·5.

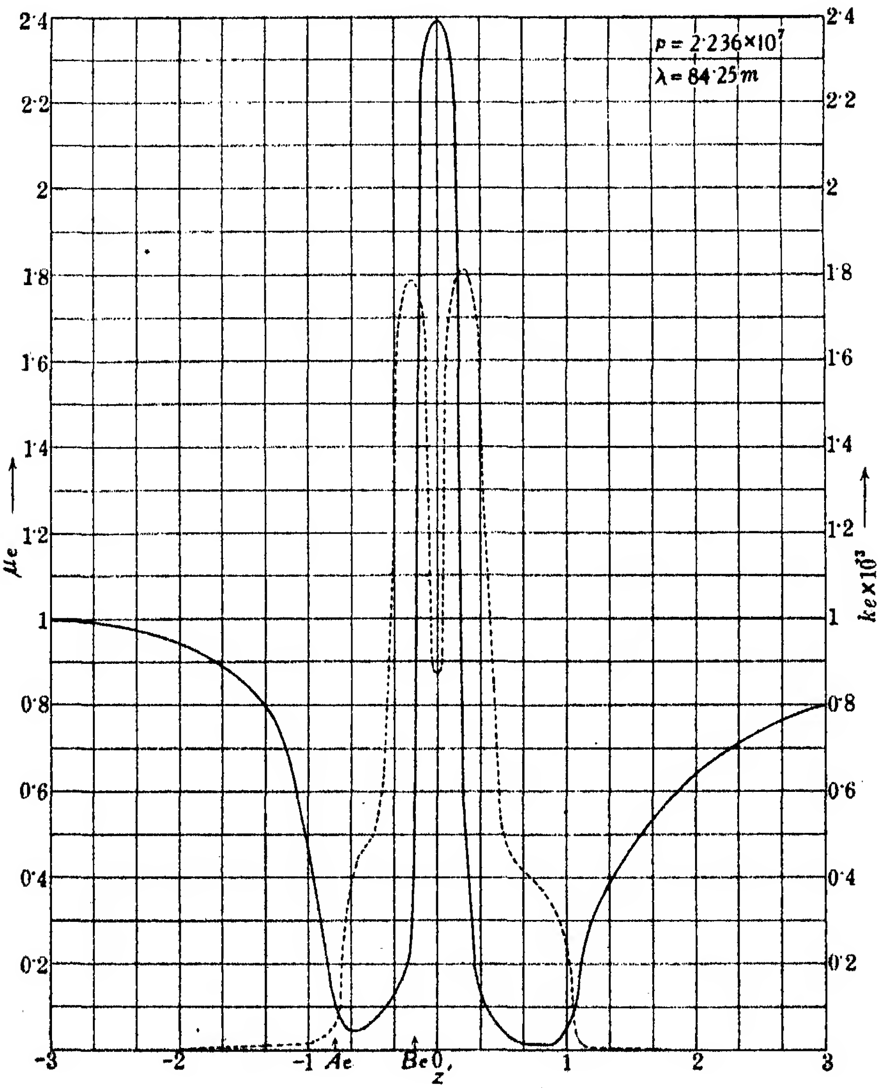


FIG. 9.

In fig. (12) $\mu_e - z'$ and $k_e - z'$ curves are drawn for $p = 4{\cdot}472 \times 10^7$ ($\lambda = 421{\cdot}3$ m.) representing curves for the frequencies less than the gyro-magnetic frequency. In this μ_e first becomes greater than unity, then it begins to fall very abruptly at $z' = -2{\cdot}3$, attaining very small values between

$z' = -2{\cdot}0$ to $z' = +5{\cdot}5$. From $z' = 6$ it again abruptly rises and ultimately becomes greater than unity. There are two maxima in the k_e-curve: (1) a big and flat one at $z' = -0{\cdot}2$ and another a very small one at $z' = -2{\cdot}5$.

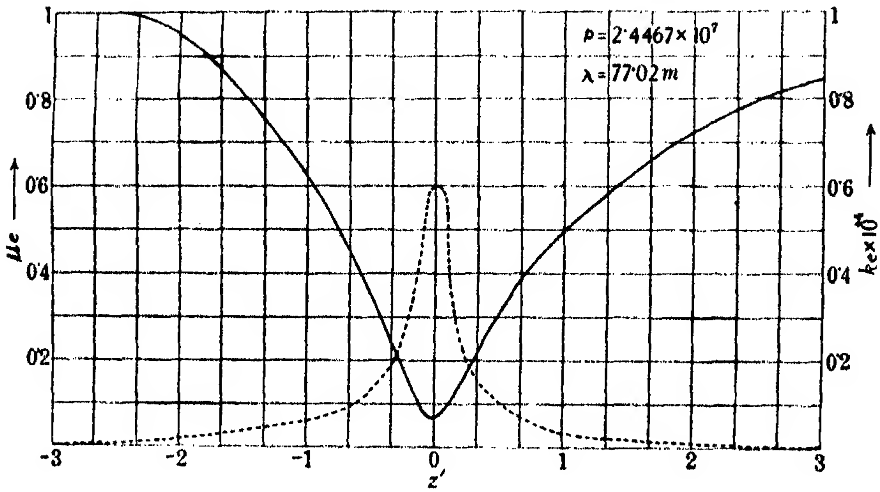


FIG. 10.

The total integrated absorption coefficient κ for the wave reflected from A_e is nearly 41.

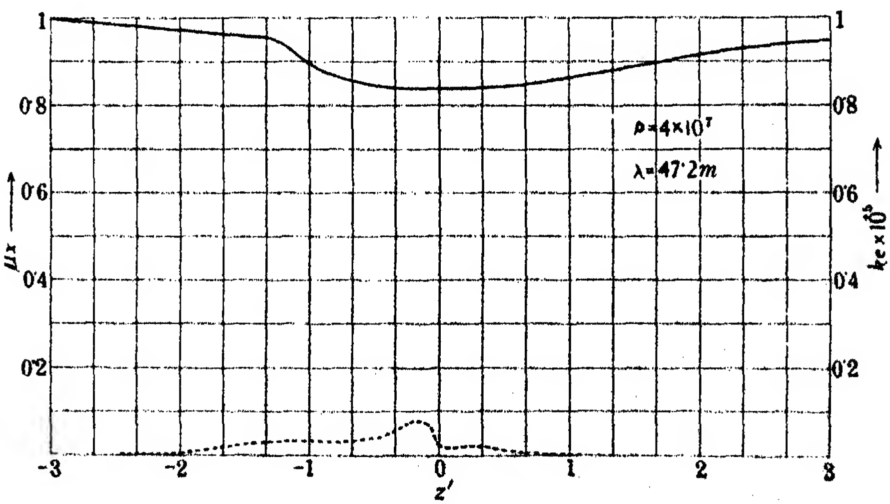


FIG. 11.

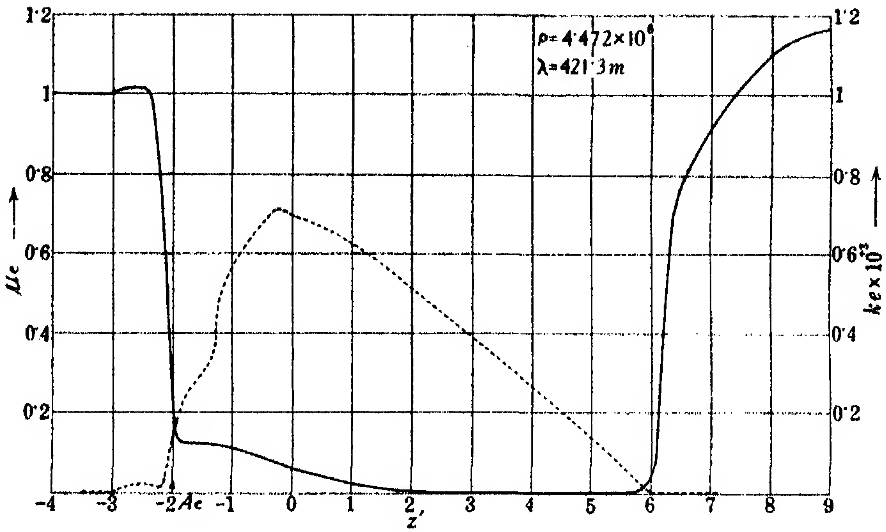


FIG. 12.

§ 3.

In the quasi-longitudinal case, i.e., when

$$\frac{4(r-\beta)^2\cos^2\alpha}{\omega^2\sin^2\alpha}>1$$

equation (1) reduces to

$$q_{0,\,e}=1-\frac{r}{\beta\pm\omega_2}\quad\ldots\quad\ldots\quad\ldots\quad\ldots\quad(8)$$

where the $+$ sign is taken for the ordinary ray, while the $-$ sign is taken for the extra-ordinary ray. After some simplifications we have from (8)

$$\left.\begin{aligned}\mu^2_{0,\,e}&=\frac{1}{2}\left[\sqrt{X_{11}^2+Y_{11}^2}+X_{11}\right]\\ \frac{c^2k^2_{0,\,e}}{p^2}&=\frac{1}{2}\left[\sqrt{X_{11}^2+Y_{11}^2}-X_{11}\right]\end{aligned}\right\}\quad\ldots\quad\ldots\quad\ldots\quad(9)$$

where

$$\left.\begin{aligned}X_{11}&=1-\frac{r(1\pm\omega_s)}{(1\pm\omega_s)^2+\delta^2}=1-\frac{p_0^2(p^2\pm pp_s)}{(p^2\pm pp_s)^2+\nu^2p^2}\\ Y_{11}&=\frac{r\delta}{(1\pm\omega_s)^2+\delta^2}=\frac{p_0^2\nu p}{(p^2\pm pp_s)^2+\nu^2p^2}\end{aligned}\right\}\quad\ldots\quad(9')$$

The above equations (9) are of the same form as (3) except that here we have $p^2\pm pp_s$ instead of p^2. Since ν^2p^2 is very very small in comparison to $p^2\pm pp_s$ (except for p very near p_s) the form of the $\mu_{0,\,e}-z'$ and $k_{0,\,e}-z'$ curves, for the same group of frequencies will be similar to those drawn for the ordinary

ray in the quasi-transverse case from (3) and (3'). Only the value of critical penetration frequency p_c will change, and here it will be given by

$$\frac{4\pi N_{o,e}^2}{m} = p_c^2 \pm p_c p_z .$$

Hence a curve drawn for a frequency p_1 in this case will be nearly similar to the one drawn for the frequency p_{11} in the previous case such that $p_{11}^2 = p_1^2 \pm p_1 p_z$. As for example the curve drawn in fig. (2) for $p = 2 \times 10^7$ will be nearly similar to the curves drawn in this case for $p = 1{\cdot}765 \times 10^7$ for the ordinary ray (taking the + sign into account) and for $p = 2{\cdot}265 \times 10^7$ for the extra-ordinary ray (taking the − sign into account) assuming that $p_z = 5 \times 10^6$.

§ 4. Discussion.

The $\mu_0 - z'$ and $k_0 - z'$ curves for the O-wave for frequencies much smaller than p_c—the penetration frequency—show that the value of μ_0 is very very small and k_0 is fairly large for a large portion of the layer. But as we approach the critical penetration frequency, the region for which μ_0 is very very small and k_0 fairly large decreases, at the same time the minimum value of μ_0 increases and the maximum value of k_0 decreases. At the penetration frequency this becomes very narrow. For still higher frequencies the value of μ_0 at $z' = 0$ goes on increasing, while the k_0-curve goes on diminishing (vide figs. (4) and (5)).

For the wave reflected from A_0 the value of κ increases as we increase the frequency. It is maximum for the penetration frequency. For the wave reflected from B_0 the values of κ are very great. It decreases as we increase the frequency and is minimum for the penetration frequency. For frequencies higher than the penetration frequency the value of κ (which is now due to the whole layer) goes on decreasing as we increase the frequency.

For the extra-ordinary ray in the Q.T. case in the $\mu_0 - z'$ curve the portions between A_e and B_e, and E_e and F_e goes on narrowing and the portion between C_e and D_e increases as we decrease the frequency, till at the gyromagnetic frequency $A_e B_e$ and $E_e F_e$ portions disappear and $C_e D_e$ becomes sufficiently broad. For frequencies less than the gyromagnetic frequency the value of μ_e remains greater than unity on both sides of $C_e D_e$ for some distance. If we increase the frequency the reverse happens, till C_e and D_e coincide and if we further increase the frequency this portion goes up till it disappears and the two maxima on either side of $C_e D_e$ coincide and form one maximun (vide fig. (8)). For still higher frequencies this maximum decreases, at the same time it becomes narrow till it disappears and B_e and E_e coincide. By further increasing the frequency the remaining portion $A_e F_e$ becomes narrow till it disappears at the penetration frequency and the curve reduces to the form shown in fig. (10). For frequencies greater than the penetration frequency $\mu_e - z'$ curve behaves as for the ordinary ray.

In the $k_e - z'$ curve in the Q.T. case there are three maxima, one at C_eD_e and the others very near to the points B_e and E_e. If we decrease the frequency the maximum at C_eD_e increases while at B_e and at E_e it decreases till they disappear at the gyromagnetic frequency. Below the gyromagnetic frequency there will again be a very small maximum near about B_e. If the frequency is increased the reverse happens, the C_eD_e maximum diminishes, while those at B_e and at E_e increase, till the maximum at C_eD_e disappears. If the frequency is further increased the maxima at B_e and E_e coincide, which on further increase in frequency diminishes.

For the waves reflected from A_e as well as from B_e κ increases as the frequency is increased and is maximum at the penetration frequency. But at the gyromagnetic frequency κ again becomes very great and decreases with further decrease in frequency. For the waves greater than the penetration frequency κ decreases as the frequency is increased which is true for the ordinary ray also.

The possibility of reflection of the wave from the point B_e is very little because κ in this case is very large. It is smaller for frequencies near the gyromagnetic frequency, but then the path difference between the rays reflected from A_e and B_e is so small that it is not possible to get the two rays separated.

Reflection from the point A_e can always be obtained except near the gyromagnetic frequency and very near the penetration frequency, where κ is large. It is due to the large value of K near the penetration frequency that we generally get weak echoes and at times a gap in the $(P'-f)$ curve when we pass from one layer to another.

For the ordinary wave reflection from the point A_0 is always obtained, but like the extra-ordinary wave this is also slightly absorbed near the penetration frequency. Due to high absorption reflection of the O-wave from the point B_0 is not possible. If there is any possibility of such reflection then it is very near the penetration frequency, but then the path difference between A_0 and B_0 is so small that it is not possible to get the two rays separated on the receiver.

By comparing the values of κ for the o- and x-wave of the same frequency it is clear that in the Q.T. case for frequencies greater than the gyromagnetic frequency the ordinary ray will be more absorbed than the extra-ordinary ray as is evident from the values of κ from figs. (1) and (7), and (2) and (6). These results clearly explain the experimental results of Wells and Berkner (1936) who obtained at Huancayo (where Q.T. case holds) that though ordinary and extra-ordinary rays are nearly of equal intensity the latter is slightly stronger than the former. For frequencies less than the gyromagnetic frequency the extra-ordinary ray is more absorbed than the ordinary ray in the Q.T. case. In the Q.L. case the extra-ordinary ray will be more absorbed than the ordinary ray for all frequencies as is evident from figs. (1) and (2).

If we compare the absorption of these two waves by taking the o-wave in the Q.T. case and the x-wave in the Q.L. case as has been done by Booker (1935) then also the x-wave is more absorbed than the o-wave.

In the non-deviating region both for the Q.T. and Q.L. case the o-wave is more absorbed than the x-wave. The maximum absorption for the o-wave in both Q.T. and Q.L. regions and for the x-wave in Q.L. region takes place near the level $z' = -1{\cdot}1$. But the maximum absorption for the x-wave in the Q.T. case takes place near the level $z' = -0{\cdot}2$. Both in the Q.T. and Q.L. cases κ is greater for the x-wave than the o-wave for the penetration frequency (vide figs. (3) and 10)).

All these curves have been drawn by assuming certain values of N_0 and ν_0. If we change the value of N_0, it will alter the value of the penetration frequency but the form of the curves for a particular group will not alter much. If we use higher values of ν_0 the $\mu - z'$ curve will be slightly raised, more prominently on the negative side of z' where μ is very small. The $k - z'$ curve will also be raised and the values of κ will increase. If we use smaller values of ν_0 the reverse happens. In drawing these curves χ is kept equal to zero. If it is also varied then for small values of χ the $\mu - z'$ curve will be like one drawn for slightly lower frequency. For sufficiently higher values of χ there will be some difference between the usual form of the curve. But it is certain that as we increase the value of χ the value of κ for a particular frequency will go on diminishing.

My hearty thanks are due to Prof. M. N. Saha, D.Sc., F.R.S., and Dr. G. R. Toshniwal, D.Sc., for their keen interest and useful suggestions.

Summary.

Curves showing variation of refractive index and absorption coefficient with height have been drawn for different frequencies for a simple layer, in the quasi-transverse and quasi-longitudinal cases. Assuming that the reflection takes place where the variation of refractive index with height is very large, the points where reflection takes place and the corresponding total integrated absorption coefficients have been calculated. It has been shown that the reflection corresponding to the condition $\mu = \infty$ is not possible. The extraordinary ray is shown to be more absorbed than the ordinary ray in all cases, except in the quasi-transverse case for frequencies greater than the gyromagnetic frequency where the reverse is the case. In the non-deviating region the extraordinary ray is less absorbed than the ordinary ray.

References.

Appleton, E. V., (1932). *Jour. I.E.E.*, 71, 642.
Appleton, E. V., (1938). *Proc. Roy. Soc.*, A. 162, 451.
Bajpai, R. R., (1937). *Proc. Nat. Acad. Sci. India*, 7, 95.
Bajpai and Mathur, (1939). (in press.)
Booker, H. G., (1935). *Proc. Roy. Soc.*, A. 150, 262.
Bose, S. N., (1938). *Ind. Jour. Phys.*, 11, 21, 121.

Chapman, S., (1931). *Proc. Phys. Soc.*, 43, 26.
Goubau, (1935). *Zs. f. H.F.T.*, 45, 181.
Majumdar, R. C., (1938). (in press).
Martyn, D. F., (1935). *Phil. Mag.*, 19, 376.
Mary Taylor, (1934). *Proc. Phys. Soc.*, 46, 408.
Pant and Bajpai, (1937). *Science and Culture*, 2, 409.
Rai, R. N., (1937). *Proc. Nat. Inst. Sci. India*, 3, 307.
Saha and Rai, (1938). *Proc. Nat. Inst. Sci. India*, 4, 319.
Wells and Berkner (1936). *Terr. Mag.*, 41, 75.

STUDIES ON THE IONOSPHERE AT ALLAHABAD.

By B. D. PANT, *M.Sc. and* R. R. BAJPAI, *M.Sc., Department of Physics, Allahabad University.*

(Communicated by Prof. M. N. Saha, F.R.S.)

(*Read April 5, 1939.*)

1. INTRODUCTION.

For the last few years since 1934 we have been studying the Ionosphere at Allahabad. But so far we generally worked on a fixed frequency of 4 mc./sec. and useful data regarding equivalent height, collisional frequency and reflection coefficient for the above mentioned frequency were collected and published.[1] The present paper deals with the study of the F-region during 1936–38. These results show that, besides the three usual conditions of reflection obtained from the assumption that radio-waves get reflected when both their refractive index and group velocity become zero, there exists another condition of reflection (Pant and Bajpai, 1937) which has been explained[2] as the one where the group velocity[3] $= 0$, and $\mu = \infty$ (Rai, 1937). Section 2 describes our apparatus, while section 3 presents a brief summary of the experimental results. Section 4 contains a detailed discussion of the results given in section 3.

2. APPARATUS.

The transmitter consisted of a simple Hartley oscillator and the pulses were generated after the method of Appleton and Builder (1932). It was run on raw a.c., and the frequency could be varied from 2 to 12 mc./sec. For different ranges different sets of coils and condensers were used.

But it was soon found that this pulse generator, though quite suitable for fixed frequency work, was not so for recording continuous (P', f) curves. Hence, another transmitter using a thyratron as pulse generator was constructed.

With slight modifications it is similar to the one described by Ratcliffe and White (1933 b). This arrangement worked so satisfactorily that it could be left running for days together without any attention.

---

[1] Toshniwal and Pant (1935); Bajpai (1936); Toshniwal, Pant, Bajpai and Verma (1936); Toshniwal, Pant and Bajpai (1937).

[2] See also Bajpai (1937).

[3] See also Goubau (1934).

As it was not possible for a single antennæ to respond efficiently throughout such a large range, a system of five antennæ was used. These were coupled to the oscillator tank circuit by means of two turns of $\frac{1}{4}$ inch copper tubing.

The receiving equipment consisted of a commercial superhet receiver in which several modifications were introduced. The automatic volume controls were entirely cut off and time constant in the circuit of the second detector was considerably reduced. The output was taken from the plate of the first I.f. amplifier through a proper bias battery to the oscillograph. A thermionic valve bridge was used for reducing the strength of the ground pulse. Our transmitter and receiver were both kept side by side so that a single worker could change the transmitter frequency continuously with one hand and keep the receiver in step with the other hand. The whole of the frequency range could be covered in about twenty minutes. The photographs were invariably supplemented by visual observations.

3. Experimental Results.

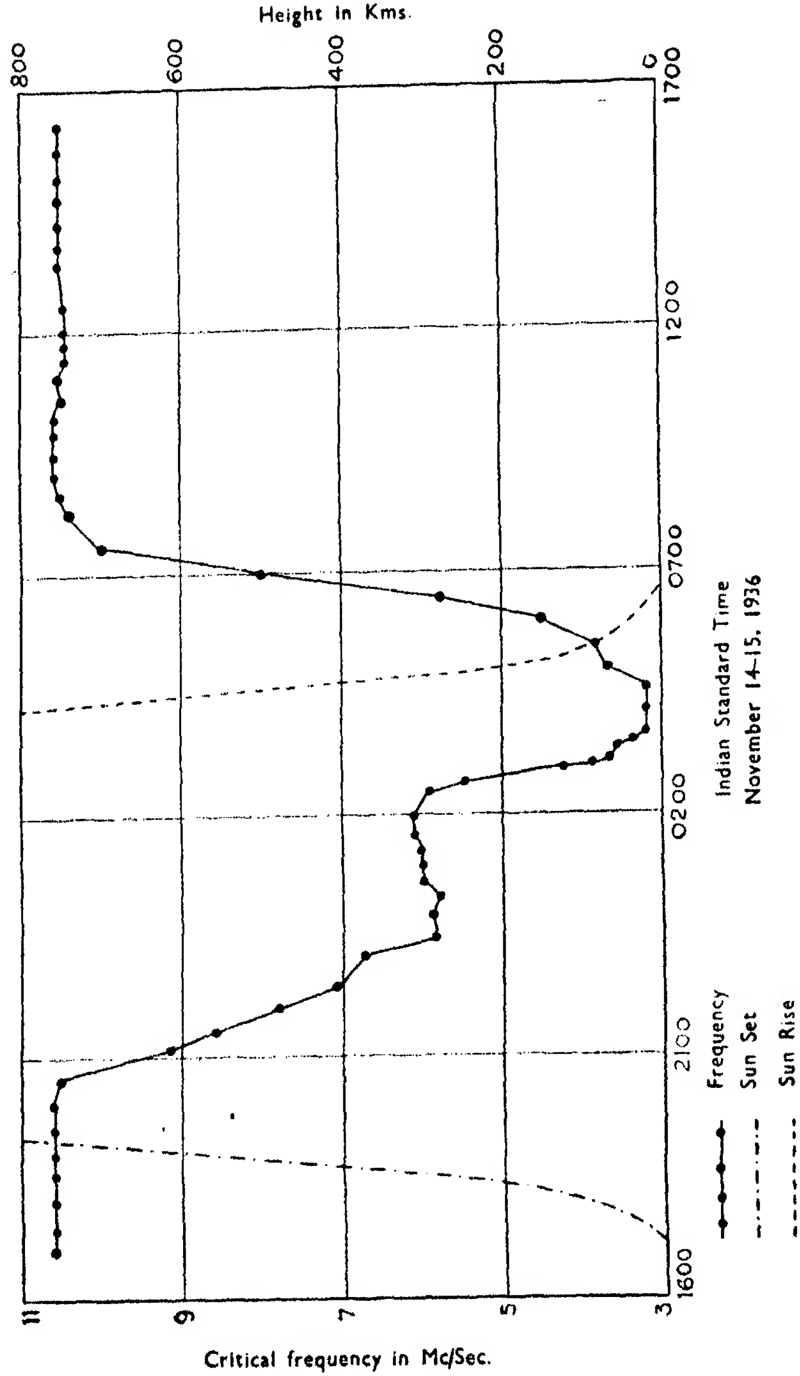
A. *Magneto-ionic splitting.*

During the daytime, generally from 8 A.M. to about midnight, no magneto-ionic splitting of the waves has so far been observed for the F-region, even when the frequency of the transmitted pulses reached the cirtical penetration frequency. On several days we could not observe this splitting even at night. Pl. 1, fig. 1, a (P', f) curve for F-region, presents one such record taken on the 13th March, 1938, at 0430 in the early morning. The usual steady increase in virtual height with the increase in the frequency of the exploring waves is present. Near the critical penetration frequency sudden increase in equivalent height is also noticed, but there is no sign of magneto-ionic splitting. This behaviour of the ionosphere at Allahabad appears to be different from that at higher latitudes where splitting is observed day and night. It appears to be due to increased absorption in the tropics.

B. *Variation of Electron-density.*

Text-figure 1 represents the diurnal variation of the critical penetration frequency for the F-region on November 14-15, 1936, and is a typical curve for early winter.[1] It is seen that ionization undergoes very little variation from about 2 hours after ground sun-rise up to about 3 hours after ground sun-set, while there is a very shallow (almost imperceptible) minimum at noon. This behaviour is different from that observed at other places (higher latitudes) where a regular increase of the electron density is noted, with a maximum at noon during winter (Gilliland, Kirby, Smith and Reymer 1937; Appleton

[1] Details of F-layer ionization are being published in the *Proceedings of the National Academy of Sciences, India.*


Height in Kms.
800
600
400
200
0
1700
1200
0700
0200
2100
1600
Indian Standard Time
November 14-15, 1936
Frequency
Sun Set
Sun Rise
11
9
7
5
3
Critical frequency in Mc/Sec.

TEXT-FIG. 1.

and Naismith 1935). Let us compare our data with those obtained at Washington.

The sun's zenith angle at mid-day at Allahabad (Lat. 25° 25′ 55″ N.; Long. 81° 55′ 0″ E.) in November will be practically the same as that at Washington (Lat. 39 N.; Long. 77 W.) in September. Therefore, we have to compare our November curves with the September curves of Washington. It is to be noticed that the post sun-set constancy of ionization is absent in the Washington curve (we have no data of the variation of electron density throughout a summer day). The night behaviour also, though similar in nature, is sufficiently different from the Washington September curve. It, however, compares well with the behaviour on a November night at Washington.

C. A New Type of Reflection from the Ionosphere.

It was during the late night hours, when the critical penetration frequency had fallen to a low value of about 4 mc./sec., that we generally observed magneto-ionic splitting. We (1937) have already reported that the difference between the critical penetration frequencies of the two magneto-ionic components varied from 0·15 mc./sec. to 0·06 mc./sec. depending on the value of the critical penetration frequency. This phenomenon is illustrated in Pl. I, fig. 2 which is a (P', f) curve obtained on October 5, 1937, at 2350; on this occasion the value of this difference $(f_x - f_o)$, was 0·1 mc./sec.[1] We observe that as the frequency of the exploring waves increases, the difference between the time retardations of the two components is seen to increase, as is usually the case, and finally the ordinary ray disappears at a frequency of 8·2 mc./sec., while the extraordinary ray does so at 8·3 mc./sec. Pl. I, fig. 3 shows the same phenomenon on 17th November, 1937, at about 0152. The ordinary and the extraordinary rays are seen to disappear at frequencies of 4·5 and 4·65 mc./sec. respectively. It is, however, remarkable that the usual asymptotic increase in virtual height (*vide* Pl. II, fig. 4) near the critical frequency is entirely absent in Pl. I, figs. 2 and 3.

We have also observed that on occasions, the difference between the critical penetration frequencies of the two components takes the normal value of 0·65 mc./sec. which is expected from Appleton's magneto-ionic theory. Pl. II, fig. 4 obtained on October 4, 1937, at 0340 presents one such example. The ordinary and the extraordinary components are seen to disappear at frequencies of 6·1 and 6·75 mc./sec. respectively. Our recent work shows that the occurrence of the smaller difference between the critical penetration frequencies of the two magneto-ionic components is rather a rare phenomenon, which usually occurs after midnight but we have not been able to find out

---

[1] We are calling the higher curve ordinary and the lower one extraordinary in accordance with the general convention. Only polarization measurements can decide this point. We have not yet carried out such measurements.

any connection between this phenomenon and any peculiar meteorological condition of the upper atmosphere.

In table 1 below we give the critical penetration frequencies for the two magneto-ionic components together with the time and date of their occurrence.

TABLE 1.

Date	Time (I.S.T.)	f_o	f_x
10-10-36	0230	7·09	7·19
10-10-36	0245	7·28	7·34
15-10-36	0250	3·96	4·10
18-10-36	0250	3·85	4·00
20-10-36	0300	3·77	3·92
15-11-36	0130	5·96	6·05
15-11-36	0200	5·96	6·05
15-11-36	0240	5·40	5·50
19-12-36	0330	3·72	4·36
23-12-36	0615	3·35	3·50
14-1-37	2320	4·35	4·50

f_o and f_x denote the critical penetration frequencies for the o-wave (ordinary) and the x-wave (extraordinary) respectively in mc./sec.

D. Another new phenomenon.—Simultaneous disappearance of o- and x-waves.

On several occasions, as the frequency of the exploring waves was increased the difference in the time-retardation of the two magneto-ionic components went on increasing as usual, but finally both of them disappeared at almost the same frequency.[1] Thus from 2330 (I.S.T.) on December 14, to 0100 (I.S.T.) on December 15, 1936, both the components disappeared at a frequency of 3·6 mc./sec. It may be mentioned that on this night the observations were taken only during this one hour and a half. Another such occasion was on the night of December 6, 1936, between the hours 0410 and 0600 (I.S.T.). This time the observations were taken throughout the night. From about 3 A.M. the penetration frequency was almost constant at 3·5 mc./sec. There was no splitting of the echoes till 0410, whereafter both the magneto-ionic components were observed. At 0430 both the components disappeared at a frequency of 3·5 mc./sec., while at 0500, 0515, 0530 and 0600 they disappeared together at the frequencies of 3·45, 3·47, 3·48 and 3·5 mc./sec. respectively. During this period we also observed for a few minutes that there were two orders of reflection present and that each of them appeared to consist of four echoes.

[1] See Best, Farmer and Ratcliffe (1937) who have occasionaly observed the two threshhold frequencies for the E-region to coincide at midday in summer. They ascribe it to strong absorption.

E. Complex Echoes.

Besides these types of reflections, we have on several occasions observed a large number of echoes on the oscillograph screen; these cannot be explained as magneto-ionic components or multiple reflections. What we observe, on such occasions, is that, besides a number of main multiple reflections (F', F'', etc.), there appears a number of echoes in between these main multiple reflections. The intensities of these echoes are generally comparatively smaller than those of the main reflections (F', F'', etc.) and they go on changing rapidly. Such echoes have been styled complex by Dr. G. R. Toshniwal and ourselves (1937) who first observed them here. Such echoes have been observed by Ratcliffe (1933 *a*), Harang (1937), Appleton, Naismith and Ingram (1937) and Bontch-Bruewitch (1935), but not much serious notice appears to have been taken of such reflections. Some of the snapshot photographs obtained on March 26, 1938, are reproduced here. Pl. II, fig. 5 obtained at 2222 clearly shows that between F' and F'' there is a number of extra echoes and although generally the complexity is greatest between F' and F'', yet sometimes we have observed that there is no complexity between F' and F'' but there appears a number of small echoes between F'' and F'''. Pl. III, fig. 6 obtained at 2230 shows multiple reflections from the E-region as well. This can be identified as the abnormal E-layer reflection. The E-reflections are generally not present during such periods. Pl. III, fig. 7, a (P', t) curve obtained at a frequency of 5·4 mc./sec. on February 19-20, 1938, between the hours 1930 and 0620 (I.S.T.), presents a very violent type of complexity. It is to be noticed that complex echoes from the F-layer persisted for several hours but no reflections from the E-region were obtained. The duration of the complex echoes varies from a few minutes to several hours. They may appear only once or several times during a night. Whenever such echoes appear they generally continue on all frequencies. Pl. IV, fig. 8 shows a (P', f) curve taken on March 13, 1938. It is seen that complexity is present throughout the record from 2·8 to 7·8 mc./sec. We did not continue the record further but visual observations showed that complexity was present even at a frequency of 13·3 mc./sec.

4. Explanation of the New Type of Reflection.

The small difference in the critical penetration frequency of the two magneto-ionic components—0·14 mc./sec. in place of the expected value of about 0·8 mc./sec.—and the variation of this difference from 0·06 to 0·15 mc./sec. with the frequency of the exploring waves, for a long time, proved to be very puzzling. These results could not be explained on the generally accepted criterion so far of reflection of radio waves, that reflection takes place from the places where the refractive indices for the o- and x-waves become zero. These results necessitated a revision of our ideas concerning the reflection of radio waves from the ionosphere, and at the suggestion of Prof. Saha, Mr. R. N. Rai (1937) of this laboratory worked out the problem on the assump-

tion that radio waves get reflected not when their refractive index becomes zero, but when their group velocity becomes zero. This analysis gave the following four conditions of reflection [1] :—

$$p_0^2 = p^2 \quad \ldots \quad (\alpha)$$

$$p_0^2 = p^2 - pp_h \quad \ldots \quad (\beta)$$

$$p_0^2 = p^2 + pp_h \quad \ldots \quad (\gamma)$$

$$p_0^2 = p^2 \frac{p^2 - p_h^2}{p^2 - p_L^2} \quad \ldots \quad (\delta)$$

where, $p_0^2 = 4\pi Ne^2/m$;

N = number of electrons per c.c. ;

$p_h = eh/mc$;

$p_{L,T} = eh_{L,T}/mc$;

h = magnetic field of the earth ;

$h_{L,T}$ = vertical and horizontal components of h ;

e = charge on the electron ;

m = mass of the electron ;

c = velocity of light in vacuo.

The first three of these conditions are exactly the same as those obtained by Appleton (1932) from the supposition that reflection takes place when the condition $\mu = 0$ is satisfied. The assumption that reflection takes place when group velocity of the waves becomes zero, however, gives us the additional fourth condition (δ) which is satisfied at the place where $\mu = \infty$. Later, Bajpai (1937) obtained all these conditions proceeding from the assumption that reflection takes place from the region where the rate of change of refractive index with height becomes large.

The condition (δ) enabled us to explain the small values of the difference between the critical penetration frequencies of the o- and the x-waves and variation of this difference with the critical penetration frequency, for if we assume that the extraordinary ray gets reflected from the level where electron concentration corresponds to the condition (δ) and not from the place where the condition (β) is satisfied, and that the reflection of the ordinary ray is governed by the usually accepted mode (α), we get from (α) and (δ)

---

[1] See Goubau (1934) who calculated the group velocity of the o- and x-waves and plotted them (after some approximation) for a number of wave-lengths using varying electron concentration. He obtained these four conditions of reflection but he did not appear to have considered the possibility of the actual occurrence of reflection according to the condition (δ).

$$f_0^2 = f_x^2 \frac{f_x^2 - f_h^2}{f_x^2 - f_L^2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

or

$$f_x - f_0 = \frac{f_x^2 f_T^2}{(f_x^2 - f_L^2)(f_x + f_0)} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

$$\doteqdot \frac{1}{2} \cdot \frac{f_x f_T^2}{f_x^2 - f_L^2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2')$$

where $f_{L,T} = \frac{p_{L,T}}{2\pi}$

while, if we assume that the reflection of the ordinary and the extraordinary waves is governed by modes (α) and (β) respectively, we obtain from (α) and (β)

$$f_0^2 = f_x^2 - f_x f_h \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

or

$$f_x - f_0 = f_x f_h / (f_x + f_0) \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

$$\doteqdot f_h/2 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4')$$

Now, a comparison of (2) and (4) shows that, for the range of wavelengths under consideration, the value of $(f_x - f_0)$ as obtained from (2) is much less than that obtained from (4). Equation (2) also shows that there will be a large variation in the value of $(f_x - f_0)$ with the critical penetration frequency, the smaller differences being expected at higher values of f_x.

In table 2 we give the values of $(f_x - f_0)$ as obtained from our experiments as well as those expected from (2) and (4).

TABLE 2.

$(f_x - f_0)$ experimental	$(f_x - f_0)$ from (2)	$(f_x - f_0)$ from (4)
0·10	0·074	0·77
0·06	0·073	0·77
0·14	0·137	0·80
0·15	0·142	0·80
0·15	0·145	0·80
0·09	0·088	0·77
0·09	0·088	0·77
0·10	0·098	0·78
0·64	0·128	0·80
0·15	0·167	0·81
0·15	0·123	0·79

For Allahabad the value of

$$p_L = 6{\cdot}617 \times 10^6$$

and $$p_h = 9{\cdot}198 \times 10^6$$

A glance at the table shows that in almost all cases where small values of the difference between the critical penetration frequencies of the two magneto-ionic components are obtained, there is a nice agreement between the experimental values of $(f_x - f_0)$ and those obtained from (2), which strongly suggests that in these cases the reflection of the x-wave is governed by the condition (δ). It is also obvious that the value 0·64 mc./sec. is obtained when the x-wave is reflected according to mode (β).

Though our experimental results find a satisfactory explanation from the theory outlined above, yet the question arises as to why, on certain occasions, the x-wave does not get reflected from regions having lower values of electron concentration corresponding to the condition (β), but is reflected from the higher electronic concentration corresponding to condition (δ). We have also to find out why, on certain occasions, the same x-wave gets reflected from two, or possibly even three, different levels in the ionosphere as observed by Toshniwal (1935) in the case of (β) and (γ) and confirmed by Leiv Harang (1936). Other striking evidence in favour of partial reflections consists in the phenomenon of sporadic E reflections when part of the energy gets reflected from this E-layer and part from the F-layer. Complex echoes present another such example. A partial explanation of such phenomena has been suggested by Saha and Rai (1937) who have shown that if the electron layer be sufficiently thin, cases may occur where only a part of the incident energy depending upon the density and thickness of the layer gets reflected,[1] and the remaining energy leaks through, to be reflected from higher regions. This leads us to revise our ideas about reflection of radio waves based on the ray treatment in which reflection is regarded as complete when $\mu = 0$, while Saha and Rai's treatment shows that reflection will be complete only when the electron barrier is sufficiently thick. Thus it appears to us that on the occasions, when we observed small values of the difference between the critical penetration frequencies of the o- and x-waves, i.e. (·15 mc. or less) the layer where the condition $p_0^2 = p^2 - pp_h$ was satisfied was extremely thin, so that the x-wave leaked through, almost completely, and then got reflected at the point where condition (δ) was fulfilled. But as Saha and Rai have not yet given any solution of the equation for the propagation of the x-wave, it is not possible for us to discuss this problem any further.

5. Explanation of Complex Echoes.

It has been pointed out before that complex echoes are due to partial reflection taking place from a number of close-lying discrete layers formed in the reflecting regions (Toshniwal, Pant and Bajpai, 1937). There was, how-

[1] This result is opposite to that arrived at from the ray treatment according to which radio waves get totally reflected from the place where their refractive index becomes zero.

ever, a difficulty in accepting such an explanation from the point of view of the ray theory, but Saha and Rai's (1937) paper has made matters clearer. Generally the observed temporal retardation between one component and another in the complex echoes is such as to give an equivalent height difference of about 20–50 kms. The actual height difference may be much less than this, being only about 2 or 3 kms., for the electron concentration in the region intervening between the two layers responsible for the complex echoes cannot possibly be much less than that in the layers, and hence the group velocity of the waves in this region will be appreciably less than the vacuum velocity of light. This means that the actual distance for which the time retardation is found to be about 20 kms. may not be more than 2 or 3 kms. only. If the thickness of the reflecting layers is also of this very order, or even less, Saha and Rai's (1937) calculations easily explain the multiplicity of reflections. The existence of a number of discrete layers lying close to one another is also supported by Leiv Harang's (1937) curves, the only difference being that his curves show the formation of such layers between the E and F-regions while we generally observed the complex echoes above the night F-layer. Harang (1937) and Appleton, Naismith and Ingram (1937) correlate such echoes between E and F with magnetic storms. The more frequent occurrence of such echoes at Troms and Moormansk, U.S.S.R. (Bontch-Bruewitch, 1934) clearly suggests a strong correlation with magnetic storms. We have also found such a correlation, but our experience is that we observe [1] such echoes even on magnetically quiet days.[2] It may, however, be due to the occurrence of local disturbances, confined within small areas, which are unable to influence the magnetic apparatus situated at a great distance. The distance between Bombay and Allahabad is nearly 800 miles, and the magnetic co-ordinates, i.e. dip angles, are respectively (25°) and (46°). Recently attention to such localized disturbances has been drawn by Chapman (1936).

We observe that amongst the complex echoes, there are some which persist for a sufficiently long time. Such reflections are illustrated in the echo patterns given in Pl. II, fig. 5 and Pl. III, fig. 6 and also in the (P', f) curve given by Harang (1937) and in the (P', t) curves given by Toshniwal, Pant and Bajpai (1937). But along with such regular echoes we also get some transient echoes appearing and disappearing at various heights. Pl. IV, fig. 9, a (P', t) curve taken on the 17-11-37 at 0328–0333 and 0337–0342 (I.S.T.), shows that besides a number of regular echoes which are due to discrete layers, there are also some irregular transient echoes. These may also be seen in the echo patterns produced by Appleton, Naismith and Ingram (1937). These irregular echoes

[1] See Toshniwal, Pant and Bajpai (1937).

[2] We are thankful to Dr. C. W. B. Normand, Director-General of the Indian Meteorological Service, and to Dr. K. R. Ramanathan, in charge of the Magnetic Observatory at Alibagh, for lending us magnetograms and for sending us regularly the reports on the magnetic character of days.

appear and disappear so very quickly that we cannot attribute them to partial reflections occurring at discrete layers lying close together. It appears to us that these are due to reflections taking place from moving electron clouds or patches of ionization. Whenever such a cloud of electrons comes in the way of radio waves a part of the energy of the radio wave may get reflected from it and reach the receiving station.

6. Acknowledgments.

Our best thanks are due to Prof. M. N. Saha, D.Sc., F.R.S., and to Dr. G. R. Toshniwal, D.Sc., M.I.R.E., for suggesting this line of work, and for useful discussions and suggestions regarding the presentation of the paper. We are especially grateful to Prof. Saha for giving us scholarships out of his personal research grant given by the Government of the United Provinces, without which this work would have been impossible. We again take this opportunity of thanking Dr. C. W. B. Normand, Director-General of Observatories, Meteorological Service, India, and Dr. K. R. Ramanathan, Meteorologist-in-charge, Colaba Observatory, for lending us magnetograms from the Magnetic Observatory at Alibagh and supplying us with information regarding the magnetic character of days.

7. Summary.

In this paper are described the results of study of the ionosphere at Allahabad from October, 1936 to March, 1938. Various types of reflections including complex echoes are described and illustrated. A typical curve showing the diurnal variation of electron density is given. The results of measurements of the critical penetration frequencies for the o- and x-waves show that at times the x-wave gets reflected from a layer where the electron concentration is given by the condition

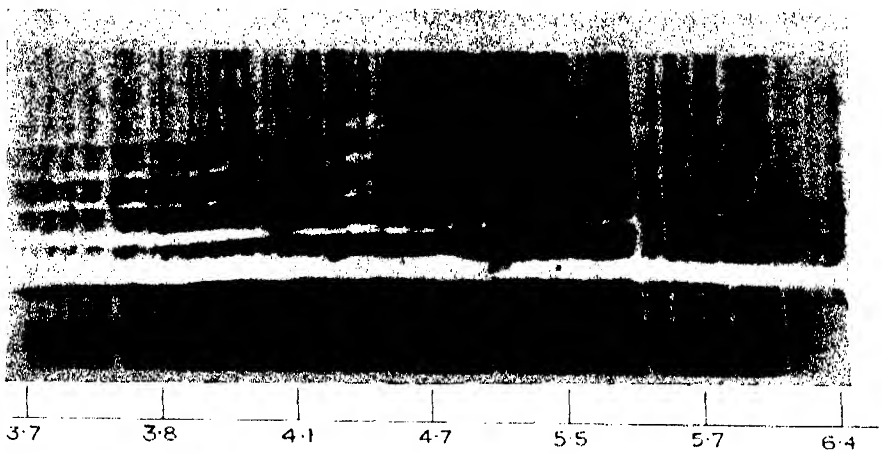
$$p_0^2 = p^2 \frac{p^2 - p_h^2}{p^2 - p_L^2}$$

instead of the usual condition $p_0^2 = p^2 - pp_h$.

References.

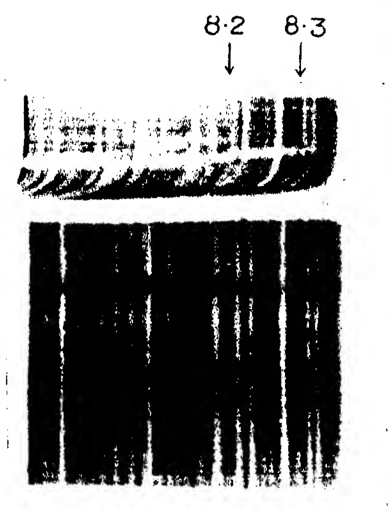
Appleton, 1932. *Jour. Inst. Elec. Eng.*, 71, 642.
Appleton and Builder, 1932. *Proc. Phy. Soc.*, 44, 76.
Appleton and Naismith, 1935. *Proc. Roy. Soc.*, A, 150, 685.
Appleton, Naismith and Ingram, 1937. *Phil. Trans. Roy. Soc.*, 236, 191.
Bajpai, 1936. *Proc. Nat. Acad. Sci. India*, 6, 40.
Bajpai, 1937. *Proc. Nat. Acad. Sci. India*, 7, 95.
Best, Farmer and Ratcliffe, 1937. *Proc. Roy. Soc.*, A, 164, 76.
Bonch-Bruewitch, 1934. *Proc. Inst. Rad. Eng.*, 22, 1132.
Chapman, 1936. The Earth's Magnetism.
Gilliland, Kirby, Smith and Reymer, 1937. *Proc. Inst. Rad. Eng.*, 25, 823.

Goubau, 1934. *H.F.T.*, 44, 17.
Harang, 1936. *Terr. Mag.*, 41, 143.
Harang, 1937. *Pub. Nors. Inst. Kosmik Fys.*, No. 11.
Pant and Bajpai, 1937. *Science and Culture*, 2, 409.
Rai, 1937. *Proc. Nat. Inst. Sci. India*, 3, 307.
Ratcliffe and White, 1933 *a.*, *Phil. Mag.*, 16, 125.
Ratcliffe and White, 1933 *b.*, *Proc. Phy. Soc.*, 45, 399.
Saha and Rai, 1937. *Proc. Nat. Inst. Sci. India*, 3, 359.
Toshniwal, 1935. *Nature*, 135, 471.
Toshniwal and Pant, 1935. *Proc. Nat. Inst. Sci. India*, 1, 87.
Toshniwal, Pant, Bajpai and Varma, 1936. *Proc. Nat. Acad. Sci. India*, 6, 161.
Toshniwal, Pant and Bajpai, 1937. *Proc. Nat. Inst. Sci. India*, 3, 337.



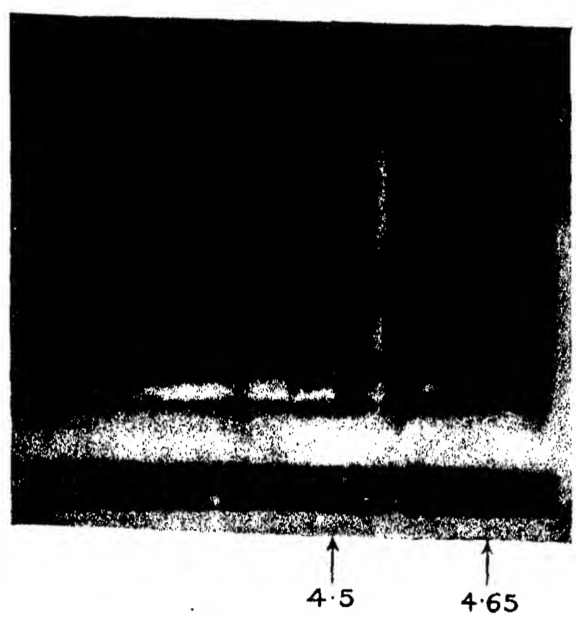
Frequency in Megacycles per Second.

FIG. 1.



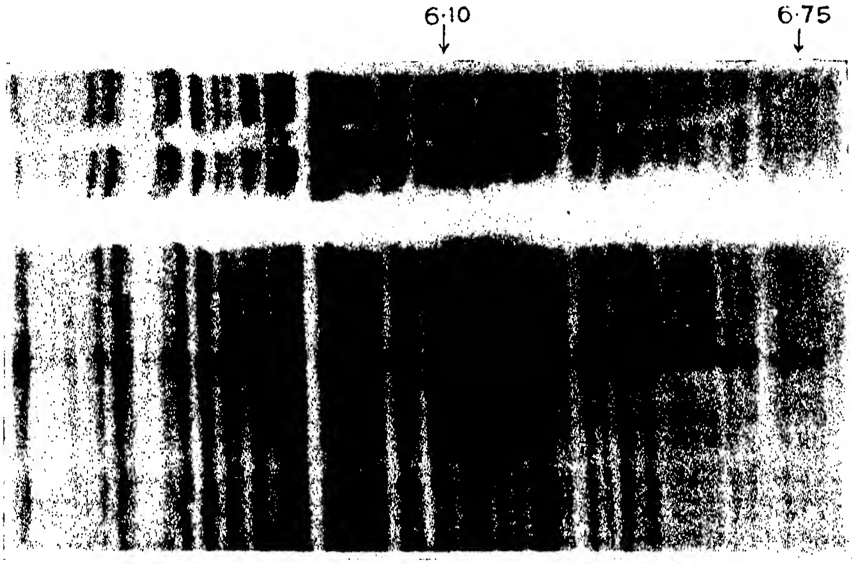
Frequency in Mc./Sec.

FIG. 2.



Frequency in Mc./Sec.

FIG. 3.



Frequency in Mc./Sec.

FIG. 4.

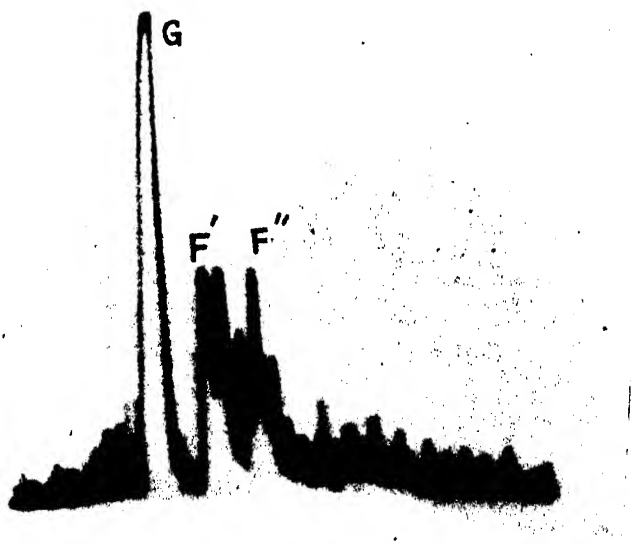


FIG. 5.

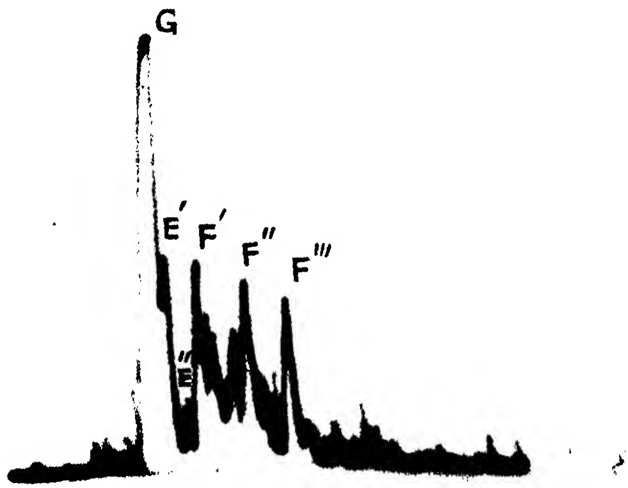

G
E'
F'
F''
F'''
E''

FIG. 6.

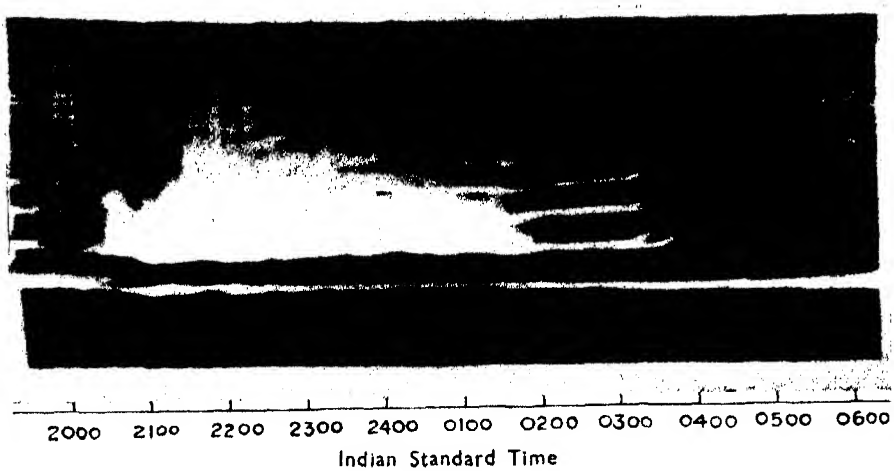
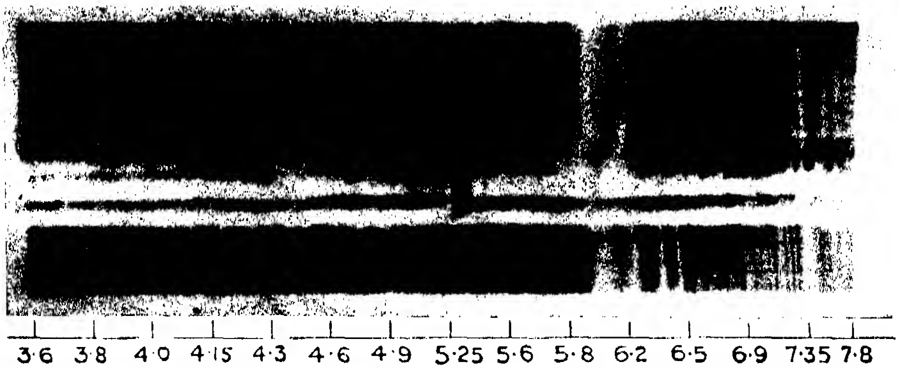

2000
2100
2200
2300
2400
0100
0200
0300
0400
0500
0600
Indian Standard Time

FIG. 7.



Frequency in Megacycles per Second.

FIG. 8.

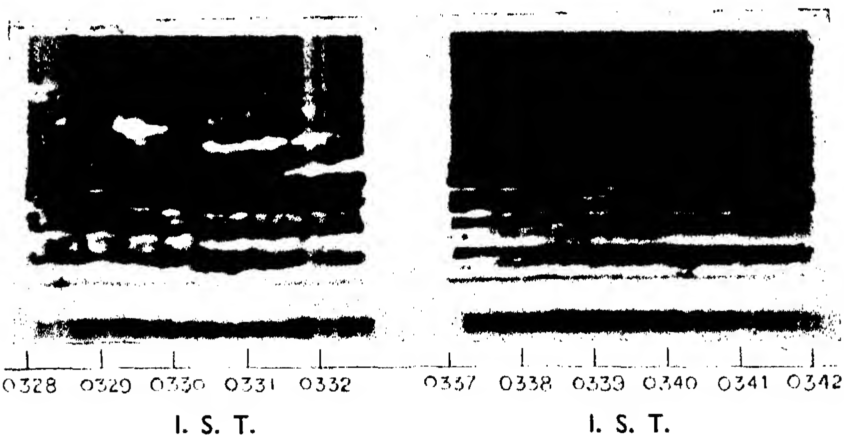


FIG. 9.

Symposium on recent work on the synthesis of naturally occurring substances.

In recent years organic chemists have devoted a great deal of attention to the synthesis of naturally occurring substances, and chemists in India have not lagged behind in developing this field of research. It had, therefore, become desirable to collect together workers on this subject from different parts of the country, and to promote a discussion that would be useful to all concerned. The National Institute of Sciences of India decided to hold such a symposium in Bombay and appointed Dr. T. S. Wheeler to be the Convener; Dr. Mata Prasad also took a prominent part in the work of organisation. The meetings were held on the 26th and 27th of September, 1938, at the Royal Institute of Science, Bombay. Prof. M. N. Saha, F.R.S., presided during the first day and the first half of the second day; Dr. T. S. Wheeler presided at the final meeting on the second day.

The symposium was formally opened by Mr. V. N. Chandavarkar, B.A., B.L., Vice-Chancellor of the Bombay University, in the University Convocation Hall. In addition to discussions on the papers presented three public lectures were given: one by Dr. S. S. Bhatnagar (read by Dr. R. B. Forster, in the unavoidable absence of Dr. Bhatnagar) on 'How Chemistry can help Indian Industries', the second by Dr. J. C. Ghosh on 'Poisonous Chemicals in Modern Warfare—Anti-gas Defence Measures', and the third by Dr. M. N. Saha, F.R.S., on the 'Geography of Space'.

In all two addresses and eight papers were presented to the symposium and some led to very excellent discussions. These papers were classified under the following heads: (A) General, (B) Bicyclic Terpenes, (C) Chemistry of Coumarins and Related Compounds, and (D) Flavones.

A.

(1) After Dr. T. S. Wheeler had welcomed those attending the symposium, Prof. M. N. Saha made a short introductory speech describing the previous symposium held by the National Institute of Sciences. Dr. J. N. Ray then opened the session by giving an address illustrated by experiments on recent developments in the study of the constitution of natural products. He dealt particularly with the growing use of the chromatographic method of Tswett in the separation of natural products which were often obtained as complicated mixtures, and he showed an interesting experiment on the purification of crude rottlerin by this method; he then discussed a variety of new techniques and reagents and concluded by describing recent advances by Indian chemists on the practical side of synthetic chemistry.

In connection with Dr. Ray's paper, Dr. R. D. Desai pointed out that though Limaye's Nidhone Process is invaluable for the synthesis of 2-acyl-resorcinols, this long process need not be followed in the case of orcinol, which reacts directly with acetyl chloride in the presence of anhydrous aluminium chloride with formation of 2-acetyl-5-methyl-resorcinol. However, acetic anhydride under the identical conditions gives the isomeric ketone 4-acetyl-5-methyl-resorcinol. Another resorcinol derivative which undergoes simultaneous β- as well as γ-substitution is resacetophenone, which reacts with acetic anhydride with the formation of 2: 4-diacetyl- and 4: 6-diacetyl-resorcinols. Other acid chlorides and anhydrides behave analogously.

Dr. Wheeler remarked that Dr. Ray's work on the oximation of compounds of weak ketonic function, such as flavones, was very interesting; they had found in this laboratory that benzylidene-coumaranones reacted ketonically like chalkones, but that flavones did not. With reference to the use of chromic acid for oxidation purposes, it had been observed that a solution of potassium chromate in acetic acid was effective as a mild oxidising agent. Dr. Wheeler also discussed the use of hydrogen bromide in place of aluminium chloride as a demethylating agent and of metallic sodium in the transformation of ortho-acyloxyacetophenones. In reply, Dr. J. N. Ray pointed out that flavones might be considered to have a quinonoid structure and that this would account for the weak ketonic function.

Mr. Limaye joined in the discussion, and stated that he hoped to be excused for not putting in a paper, although he had sent in an abstract which had to be withdrawn under unavoidable circumstances. Referring to the Nidhone Process, he said that it was specially developed for the synthesis of 2-acyl-resorcinols in connection with his work on the synthesis of a natural product, Karanjin, which he had isolated at the Ranade Institute, from Karanj—a leguminous plant—*Pongamia glabra*. The constitution of Karanjin arrived at analytically indicated that a 2-resorcinol derivative was necessary as a starting material for its synthesis. No such suitable substance or a method for its preparation was described in literature. Therefore, he started with the readily available resorcinol and through 4-methyl-umbelliferone (Pechmann)—acylation-Fries transformation—separation of the isomeric acyl-4-methyl-umbelliferones—and alkali treatment—obtained 2-acyl-resorcinol. Although the individual steps were known, their particular combination towards achieving a definite end constituted the Nidhone Process for the synthesis of 2-acyl-resorcins. He then informed the audience that the process could be extended both in homologous and analogous directions, and that the results were being published in the *Rasayanam*, in collaboration with numerous students. The latest development, he continued, was by his son, Mr. S. D. Limaye, who had extended the process to the synthesis of 2-acyl-4-alkyl-resorcinols; and a paper had been sent to the Lahore Session of the Indian Science Congress.

Referring to the varied uses of the process he wished to point out that the first synthesis of a Furocoumarin, representatives of which occur in nature, was effected by him through the Nidhone Process.

Dr. Amin Tyabji mentioned the reversal of the Ponndorf Reaction, first applied by Oppenauer and found to be very useful in the oestriol and cortical harmone group (T. Reichstein). The Oppenauer Reagent consists of aluminium butoxyde.

Dr. R. C. Shah said that chloranil was also used by Robinson for the oxidation of leucoanthocyanins. With regard to this Dr. J. N. Ray stated that Robinson had used the reagent for oxidation of leucoanthocyanins, but had got coloured amorphous products and not the anthocyanins.

Various recent synthetic methods :—

Shah's use of aluminium chloride for Pechmann Reaction.

Dr. R. C. Shah stated that he would deal with the subject in the full paper which he had contributed.

Shah's work on C-alkylation of phenols. Dr. Shah described the simple and direct synthesis, which had been achieved through this process of nuclear alkylation, of rhizonaldehyde and rhizonic acid, which are related to important lichen acids, and which had been synthesised by previous workers by long and cumbersome methods. He then gave his view of the probable mechanism of nuclear methylation of polyhydroxy-phenolic derivatives for which no explanation has been hitherto available. Taking the typical case of resacetophenone, he suggested that the 3-methylation was due to the addition of methyl iodide to the double bond between carbon atoms 3 and 4, which becomes fixed due to the stabilisation of one of the Kekule forms of the benzene nucleus owing to chelation between the 2-hydroxy and the acetyl group.

Dr. J. N. Ray then replied in detail to the various points which had been raised.

(2) In the absence of the author Dr. T. S. Wheeler read Dr. P. C. Mitter's paper on the history of research in organic chemistry in India from 1896 to 1923, and pointed out that organic research in the west of India had only begun in about 1920, so that Bombay had at first lagged behind other centres in India. However, it had now almost overtaken the older centres, and it was hoped that it would soon rival them in quantity and quality.

B.

(3) Dr. P. C. Guha opened the proceedings on the second day with an address, illustrated by lantern slides, on the work on bicyclic terpenes which had been proceeding in recent years in his laboratory at Bangalore, and

described research on the synthesis of a number of members of the series. He also discussed a new possible total synthesis of camphor.

Dr. R. D. Desai congratulated Dr. Guha on his lucid and illuminating address describing the brilliant work done by him and his students at Bangalore. He said that those who saw the beautiful slides must have thought it an easy task to carry on the work, but those who have had the practical experience of handling hydroaromatic compounds can realise the tremendous difficulties involved. Even the synthesis of one natural product or a product which can throw light on the constitution of an important natural product is a creditable achievement. Dr. Guha has to his credit the synthesis of norpinic acid, umbellulanic acid, unbellulonic acid, carane, and thujone. His use of diazomethane and dimethyldiazomethane will form classical examples in this branch of chemistry. Dr. Desai said that there were two or three points which he wished to discuss as he had practical experience of dealing with them. Firstly, he had attempted the synthesis of *nor-camphoric ester* by condensing the disodium salt of the Guareschi imide from acetone and cyanacetic ester with ethylene dibromide or ethylene di-iodide, but not a trace of the expected compound was obtained. As Dr. Guha had been able to condense tetraethylene dibromide, Dr. Desai felt his own experiments require revision.

The synthesis of camphononic acid has been achieved by them by exactly the same method as Dr. Guha had used, and they had also subjected the β-aroyl-proponic esters to the Reformatsky Reaction. The chief difficulty is with the yields in the first case. Other stages go well. Finally, in the hope of preparing camphoronic acid, which is an important substance in the oxidation of camphor, in one step, Dr. Desai said he had tried the condensation of the cyanohydrin of dimethylacetoacetic ester with ethyl sodiocyanoacetate. The yield in this case was not satisfactory, though the lower homologue reacted favourably.

Dr. J. N. Ray said that he wished to draw Dr. Guha's attention to the Ponndorf's reagent which would serve his purpose of reduction of the keto-group without affecting the double bond. It might be of help to him in his synthesis of lauronolic acid.

C.

(4, 5) Dr. D. Chakravarti's paper on the synthesis of coumarins and chromones was read, in his absence, by Dr. R. C. Shah in combination with his own paper on the same subject. Dr. Chakravarti reviewed the various synthetical methods which had been applied to the preparation of derivatives of coumarins and chromones, and also discussed the methods used to distinguish coumarins from the isomeric chromones. Dr. Chakravarti and Dr. Shah both described new methods, which had been worked out in their laboratories for the synthesis of coumarins. Dr. Shah also described the synthesis of 5-hydroxycoumarin.

In opening the discussion on the papers on the chemistry of coumarins and related compounds, Mr. Limaye congratulated Dr. Shah and his students

on their discovery of a new condensing agent (aluminium chloride) for the Pechmann Reaction, which had led to the formation of 5-hydroxycoumarins. He stressed the importance of the isolation of even minute quantities of isomers that are formed in some reactions. Thus in the preparation of 5-hydroxy-4-methyl-coumarin described by Dr. Shah, the previous isolation of this compound, although formed in very minute quantities along with the corresponding chromone, by Mr. Kelkar at the Ranade Institute facilitated the identification of Dr. Shah's compound. The second point that he wished to bring to the notice of those interested in distinguishing chromones from coumarins by the formation of a styrene derivative was a case first observed in his laboratory by Mr. Kelkar where two molecules of a chromone reacted with one molecule of an aldehyde.

Dr. Desai drew attention to the fact that the method of synthesising coumarins from ö-hydroxy-alkyl ketones was studied independently of Dr. Chakravarti, at Aligarh by himself and his students. The method would be specially useful for 7-hydroxycoumarins from orcinol which usually gives only the 5-hydroxycoumarins.

Regarding differentiation between coumarins and chromones, the action of bromine in the cold on the glacial acetic acid solution of the compound concerned had been used at Aligarh with advantage. The chromone gives a perbromide which is insoluble in acetic acid while the coumarin gives the 3-bromo-compound. The chromone can be regenerated by adding the perbromide to sulphurous acid solution.

Regarding Dr. Shah's use of aluminium chloride, Dr. Desai felt he deserved congratulations, for this method has made two new types of compounds available, e.g. the 5-hydroxycoumarins and γ-aldehydes from hydroxy-ketones. These compounds have great synthetic value, and as they are now readily accessible, new types of compounds can easily be made.

Regarding the inhibiting effect of alkyl groups in the Pechmann condensation, Dr. Desai inclined to the belief that it is partly steric and partly polar. The allyl and benzyl groups have less effect even than the methyl group. It would be no exaggeration to say that a new chapter in the chemistry of coumarins had been opened with the discovery of furo-coumarins and 5-hydroxycoumarins.

Dr. K. Venkataraman said that the difficulty in distinguishing between isomeric coumarins and chromones appeared to be somewhat exaggerated in view of the present knowledge of the properties of the two types of pyrones. Colour reactions, such as those involving the use of sodium amalgam and alcohol, magnesium and hydrochloric acid, or glacial acetic acid and sulphuric acid, were generally adequate for the distinction of coumarins and chromones.

In an attempt to synthesise fraxetin (Bharadwaj and Venkataraman, *Proc. Ind. Sci. Cong.*, 1937, 153), the persulphate oxidation of 7:8-dibenzyloxycoumarin was studied with the object of preparing the 6-hydroxy-

derivative, which could then be methylated and debenzylated to yield fraxetin. The oxidation, however, did not proceed as desired.

While Dey and Lakshminarayan (*J. Ind. Chem. Soc.*, 1932, *9*, 153) noticed that β-naphthol condensed with ethyl acetoacetate to give a chromone, the α-pyrone, and not β-naphtha*iso*flavone, is obtained with *o*-formylphenylacetic ester.

Dr. Wheeler described the synthesis of the 2-methyl-benzocoumarin, which had lately been effected in the laboratories of the Royal Institute of Science.

Dr. R. C. Shah stated that the influence of the substituent in the acetoacetic ester molecule on coumarin and chromone formation in the condensation of β-ketonic esters with phenols had been previously studied to some extent, and it has been found that the Pechmann condensation is retarded by an alkyl substituent, the effect increasing with the bulk of the alkyl group. He had studied the Pechmann condensation of α-acetoglutaric ester and found that it is more reactive than α-ethyl or α-propyl-acetoacetic ester. The CH_2-CH_2-COOEt group in spite of its much heavier bulk has less retarding effect than the lighter groups ethyl and propyl. He and his students had also found that the retarding effect of the 4-carbethoxyl group in the resorcinol nucleus is less than that of 4-nitro group as methyl β-resorcylate condenses with α-methyl, α-ethyl, α-propyl, and α-butyl-acetoacetic esters, whereas 4-nitroresorcinol condenses only with unsubstituted acetoacetic ester.

The method described by Chakravarti and Majumdar for the synthesis of coumarins through the Reformatsky Reaction on *o*-methoxy ketones had, Dr. Shah said, been used previously by Mitter and Paul and recently, independently, by Desai. He and his students had modified Canter and Robertson's method for converting coumarins into *o*-methoxy cinnamic acid; the modification consisted in the addition of dimethyl sulphate first and then alkali, instead of in the reverse order as in Canter and Robertson's original method. The modified method gives excellent results and has succeeded in several cases in which the earlier method has failed.

Dr. Shah also stated that Robertson had given a plausible explanation of the formation of chromones and coumarins in the condensation of β-ketonic esters with phenols, which is supported by some experimental evidence.

In reply to Dr. Venkataraman's suggestion that coumarins and chromones could be distinguished by the colour reactions with acetic acid—sulphuric acid, Dr. Shah stated that it was a valuable suggestion and that he had, himself, used hydrochloric acid for the purpose.

(6) Dr. K. S. Narang described the work, which he had carried out under the guidance of Dr. J. N. Ray, on the constitution of rottlerin and discussed the structure which Dr. Ray and himself had been led to assign to it.

Dr. Venkataraman and Dr. Wheeler asked a number of questions regarding alternative possibilities for the structure of rottlerin, and Dr. Narang answered them in detail.

D.

(7) Dr. K. Venkataraman gave an account of the work, which had been carried out in Lahore by himself and his collaborators, on the synthesis of a number of flavones and isoflavones. He also pointed out possible methods for the synthesis of Primetin.

Dr. R. C. Shah suggested that in Dr. Venkataraman's modified isoflavone synthesis, sodamide may probably be found useful, as the condensation of phenyl-benzyl ketones with ethyl formate was a typical Claisen ester-ketone condensation, in which sodamide was known to be superior to other agents like sodium or sodium ethoxide. Dr. Shah also described the direct formation of a flavone derivative by the action of pyridine and benzoyl chloride on 5-hydroxy-4-methyl-6-acetyl-coumarin at a high temperature. He suggested that this was probably due to the migration of the *o*-benzoyl group from the simple benzoyloxy derivative first formed to the $COCH_3$ group in the presence of pyridine, followed by ring closure to a flavone.

(8) Dr. Desai described the isolation of a flavonol which he believed to be quercetin 5- or 4′-methyl ether from the colouring matter of the yellow flowers of *Thevetia Nerifolia*. He discussed possible methods for the synthesis of this compound.

Dr. K. Venkataraman said that the flavonol, considered by Dr. Desai to be quercetin 5- or 4′-methyl ether, must be the latter. Whatever the method of methylation at the disposal of the plant may be, the relative difficulty of methylating the 5-hydroxyl must be the same as in the laboratory and it is very unlikely that the 5-hydroxyl could be methylated while the other four hydroxyls in quercetin remain unaffected. The simplest test of the position of the methoxyl would be the synthesis of quercetin 4′-methyl ether by the Robinson Reaction between ω-benzyloxyphloracetophenone and *o*-benzyl*iso*-vanillic anhydride, followed by alkaline hydrolysis and debenzylation.

(9) Dr. R. C. Shah discussed the work, which was being carried out in Bombay, on the synthesis of Oroxylin-A and of Wogonin.

(10) Owing to lack of time, Dr. T. S. Wheeler's paper on the synthesis of naturally occurring flavones from chalkones was taken as read.

The discussions taken as a whole were then summed up by Dr. T. S. Wheeler.

List of Papers read at the Symposium on 'Recent Work on the Synthesis of Naturally Occurring Substances' held at Bombay.

(September 26-27, 1938.)

A. General.

1. Some Recent Developments in the study of the Constitution of Natural Products. By J. N. Ray.
2. Researches on Organic Chemistry in India (1896–1923). By P. C. Mitter.

B. Bicyclic Terpenes.

3. Synthetic Investigations in Bicyclic Terpenes. By P. C. Guha.

C. Chemistry of Coumarins and Related Compounds.

4. Synthesis of Coumarins and Chromones. By D. Chakravarti.
5. New Synthetical Methods in Coumarin Chemistry. By R. C. Shah.
6. The Constitution of Rottlerin. Part III. By K. S. Narang, J. N. Ray and B. S. Roy.

D. Flavones.

7. Synthetical Experiments in the Flavone and Isoflavone Groups. By K. Venkataraman.
8. The Colouring Matter of the Yellow Flowers of *Thevetia Nerifolia* (Apocyanaceæ). By R. D. Desai and S. Zafaruddin Ahmad.
9. The Constitution of Oroxylin-A. Part II. Attempted Synthesis of Oroxylin-A and the Synthesis of Wogonin. By R. C. Shah, C. R. Mehta and T. S. Wheeler.
10. Synthesis of some Naturally Occurring Flavones from Chalkones. By T. S. Wheeler and Collaborators.

SOME RECENT DEVELOPMENTS IN THE STUDY OF THE CONSTITUTION OF NATURAL PRODUCTS.

By J. N. RAY, *D.Sc., F.I.C., F.N.I., Professor of Organic Chemistry, Punjab University.*

(*Read at Symposium, September 26-27, 1938.*)

In view of the limited methods at our disposal for the determination of the structure of an unknown natural product, any advance in this direction is doubly welcome. In recent years, most striking results have been obtained in the isolation of substances occurring in minute amounts by the chromatographic method devised by Tswett. It is now possible to handle small amounts of material and isolate relatively pure specimens by this method.[1]

Another advance in the method of isolation is the molecular distillation at 10^{-3} to 10^{-7} mm. By this process, sterols, natural oils, fats, vitamines have been purified. Substances melting at fairly high temperature with decomposition, e.g. vasicine, can be purified by sublimation at low pressure.

Girard's reagent T and P (i.e. carbohydrazido trimethyl ammonium chloride and carbohydrazido pyridinium chloride) have been valuable in the isolation of ketonic substances particularly rare ketones of the sexual hormone group.

---

[1] Evenness of packing of the tube is of the utmost importance and is best achieved by filling with a cream of solvent and adsorbent, the former being drawn off by slight vacuum. The adsorbent column is to be kept covered with the solvent throughout the experiment so that dropping liquid does not disturb the upper layers. The solution to be separated should be drawn in by a syphon. The following adsorbents have been used:

(*a*) Aluminium oxide (nach Brockmann),
(*b*) Fuller's earth,
(*c*) Sugar (in case of chlorophyll),
(*d*) Calcium hydroxide (in case of carotonoids—Vitamin A, etc.),
(*e*) Calcium carbonate, and
(*f*) Magnesium oxide.

The solvents chosen usually are: (*a*) petroleum, (*b*) carbon bisulphide, (*c*) ether, (*d*) chloroform, (*e*) water. Pyridine alcohol, acetone or the original solvent plus another are suitable for elution.

By forming a chromatogram of an ethereal solution of Kamala powder we have obtained six distinct zones which we are investigating. If a mixture of rottlerin (0·1 g.) with the yellow substance (0·1 g.) accompanying rottlerin described by us is absorbed in dry ethereal solution on alumina, the two zones are sharply separated. Rottlerin, once crystallised, shows the presence of a second darker zone when analysed chromatographically.

When the substances are colourless, the absorption can be done in a quartz tube and the zones detected by their fluorescence in ultra-violet light.

Certain substances containing ketonic groups showing very weak ketonic function can now be converted into oximes by a new method of oximation and the oximes purified. Such substances as flavones give oximes by this method. The value of this method of separation lies in the fact that certain hydroxy substituted flavones do not give oximes under the conditions and hence a separation is possible when a mixture of certain types of flavones is present in the crude product.

Ketonic substances containing sensitive groups can be isolated via the corresponding alcohols by means of the Ponndorf's reaction. This reaction consists in the smooth reduction of carbonyl compounds to the corresponding alcohols by aluminium *iso* propoxide in *iso* propyl alcohol. The product can be isolated as phenacyl derivative and then purified. The reagent is nearly specific for a ketonic group and under the conditions of the experiment neither a nitro nor an $\alpha\beta$ double bond is reduced. The method has its limitations in that highly enolic ketones or substances which form insoluble aluminium salts resist reduction.

Oxidation of natural products :—

(*a*) Recently lead tetra acetate has been extensively used as an oxidising agent. It has advantage over lead dioxide, in that it is soluble in some organic solvents. Other salts of quadrivalent lead, such as lead benzoate, etc., have been used. R. Criegee found that glycols were oxidised by lead tetra acetate and the ketonic or aldehydic products can be easily isolated in good yields. The process is specific in that 1:3, 1:4, 1:5 diols, aldehydes and ketones are unaffected. Unsaturated natural products can now be converted into the corresponding 1:2 diols by suitable methods and the glycols thus formed can be further oxidised with lead tetra acetate. This method has recently been applied by us in the case of rottlerin and some valuable information as to its constitution obtained.

(*b*) Chromic acid has been used for the preparation of unsaturated alcohols or ketones from olefines. But the yields are unsatisfactory. The oxidation with chromic acid is often complicated by side reactions, numerous instances of which can be found in literature. Karrer has obtained valuable results in the oxidation of β-carotene by chromic acid. The dihydroxy β-carotene produced has been oxidised to semi β-carotenone by the Criegee reagent.

(*c*) In 1927, Winterstein discovered that a 1:2 glycol in ether can be converted into 1:2 diene by phosphorus di-iodide. Kuhn has applied this method in the preparation of polyenes.

(*d*) Malaprade has found that poly alcohols can be irreversibly oxidised by iodic acid. This method has undoubted possibilities.

(*e*) Perbenzoic acid has been used for the quantitative estimation of double bond. Milas has introduced percamphoric acid as a substitute as it is stabler than perbenzoic acid. It cannot be used when the double bond is in $\alpha\beta$ position to a carbonyl group. Perbenzoic acid has been considerably used in

the oxidation of natural products. Sometimes the course of reaction is complex as was found by Perkin, Ray and Robinson in the oxidation of deoxy trimethyl brazilone. Recently Böhme has introduced a new substitute, namely monoperphthalic acid. Plummeror and Reindel found that butadiene hydrocarbons give 1: 2 oxide and no 1: 4 additions take place. Rottlerin in which a conjugated chain is suspected also gives a 1: 2 oxide.

(*f*) *Chloranil.* Robinson has used this oxidising agent in building up *iso* quinoline ring system from suitable side chains.

(*g*) *Selenium dioxide.* Since the introduction by Riley of this valuable oxidising agent extensive use of it has been made. Selenium dioxide acts on a variety of substances in alcohols, xylene, nitro-benzene or dioxan.

(1) Removal of hydrogen: ethyl succinate gives ethyl fumarate and acetonyl acetone gives diacetyl ethylene. Piperitone is converted into thymol.

(2) Oxidation of reactive methylene group: Simonsen has converted camphor into camphor quinone. Cyclohexanone gives cyclohexadione. β-diketones give triketones. Malonic ester gives mesoxalic ester. Diphenyl methane gives benzophenone. Anthracene gives anthraquinone.

(3) Direct addition of oxygen: acetylene gives glyoxal. Ethylenes are either attacked at the double bonds or at an adjacent methylene group. Oxidation of tetra hydro rottlerine methyl ether with selenium dioxide has given an unsaturated substance which liberates benzaldehyde with alkali showing two atoms of hydrogen have been removed whilst the other pair of hydrogen is unaffected. Therefore the conclusion is drawn that the hydrogen atoms removed must be attached to carbon atoms in $\alpha\beta$ position to a carbonyl group. Venkataraman has successfully employed selenium dioxide in the flavone series.

Hydrogenation of natural products :—

Hydrogenation processes can be divided into the following different groups:

(*a*) By noble metal catalysts, e.g. Pt and Pd, at ordinary temperature and pressure in the finely divided state either alone or deposited on suitable supports, e.g. barium sulphate, strontium carbonate, Kieselguhr, etc. The most popular catalyst is Adam's platinic oxide catalyst which perhaps owes its enhanced activity to traces of sodium. Adam's catalyst has been used for the micro estimation of unsaturation.

By regulating the uptake of hydrogen it is now possible to isolate products in the intermediate stages.

Recently the possibilities of rhodium have been investigated. The present indications are that it is more effective than platinum. The reduction of veratrylidine methoxy chromanone by palladium was found by Perkin, Ray

and Robinson to give an oxygen-free product whilst Pfeiffer using platinum obtained the corresponding veratyl chromanone. This would indicate that in some cases palladium is more efficient than platinum.

(*b*) Raney introduced a new form of nickel catalyst with enhanced reactivity. In some cases Raney nickel effects reduction at room temperatures, e.g. in the reduction of acetone to *iso* propyl alcohol. Dupont reports that selective hydrogenation is possible with Raney nickel and that with appropriate amounts of hydrogen, ethylenes can be isolated from acetylenes. Platinum salts and sodium hydroxide exert promoter action on Raney nickel.

(*c*) *Electrolytic reduction* is particularly suited in the case of N-CO linking. Selectivity is achieved by altering the current density and the time of reduction. Ray and collaborators found that several intermediate products can be isolated in the reduction of vasicine. There is also a hydrogenolysis of a nuclear C-NH bond because the ring is under strain.

(*d*) Adkins has exhaustively investigated the copper-chromium oxide catalyst in the liquid phase hydrogenation under pressures of 100–200 atmospheres—and has recorded circumstances under which hydrogenolysis occurs.

Dehydrogenation :—

(*a*) In 1927, Diels showed that Se can be used in place of S in the dehydrogenation of organic compounds. The temperature used is usually 280°–350°, at higher temperatures rearrangements occur. Fully saturated rings resist dehydrogenation, e.g. decalin is unaffected at 340°–360° but at higher temperatures naphthalene can be obtained. Angular methyl groups are extruded and the migration of methyl occurs. Simple methyl groups also migrate under certain conditions. At 420°, alkyl groups migrate from α to β position in naphthalene.

During selenium dehydrogenation, hydrogenation of side chain is frequently observed. Selenium dehydrogenation of sterols and related bodies result in the extrusion of the angular methyl groups. Cook *et al* found no extrusion of angular methyl group at 320° in some cases. There is reason to believe that the migration of angular methyl is bound up with the elimination of the side chain. Long side chains from C_{17} are eliminated and a methyl group migrates to this position from C_{13}. In some cases a chrysine derivative is formed by ring enlargement. Ruzicka found that α and β methyl hydrindenes give naphthalene at 450°. Hydrindenes with longer and more complex side chains give naphthalenes and not alkyl naphthalenes. Ring shortening occurs in the case of cyclo-heptane and cyclo-octane which give toluene and xylene respectively. Spiro-compounds have been found to rearrange to linear analogues by Clemo, Sen Gupta and others.

Selenium generally eliminates oxygen containing groups but Kon observed the survival of a methoxy group in some cases. Carboxy group is generally eliminated and keto suffers reduction.

(*b*) Catalytic dehydrogenation: Platinum, palladium, rhodium and iridium have been used for dehydrogenation. Zelinsky has studied the kinetics of dehydrogenation. With these metals, migration of alkyl groups seldom occurs except in some special cases. Generally there is no difficulty in dehydrogenation of fully salinated mono or polycyclic compounds except in cases where a quaternary carbon atom occurs. Zelinsky was unable to dehydrogenate 1 : 1 dimethyl cyclo-hexane. Ruzicka, however, has succeeded in getting 90% yield of retene from abietic acid.

Attempts are being made at Lahore to effect dehydrogenation in liquid phase with Pt and various promoters.

Various recent synthetical methods :—

Limaye and collaborators have made 2-acyl resorcinols accessible for synthetic purposes by the 'Fries' migration and subsequent hydrolysis of acyloxy-coumarins.

Shah has discovered a new use of aluminium chloride as a reagent for Pechmann reaction. Coumarins otherwise inaccessible are available by this method.

Wheeler and colleagues have succeeded in demethylating a methoxy ortho to a ketonic group. Wheeler has made the important observation that O-hydroxy phenyl styryl ketones which normally yield benzylidine coumarins with alkali can be converted into flavones by simple heating, or treatment with potassium cyanide in alcohol.

Chakravarty has made an exhaustive study of the Pechmann reaction and laid down important generalisations as to the course of the reaction.

Venkataraman and his collaborators have thrown considerable light on the mechanism of Allan-Robinson reaction.

Guha has found in diazomethane and analogues a valuable weapon and has succeeded in effecting numerous syntheses by the Buchner-Curtius reaction of terpene derivatives.

Bardhan and Sen Gupta's classical work on the synthesis of hydrophenanthrene has opened a new field.

Mitter has found that a trace of water sometimes moderates a violent Friedel Craft's reaction.

Shah has investigated C-alkylation of phenols by dimethyl sulphate and alkali. Various C-alkylated phenols are now easily accessible.

The above very imperfect summary gives only a slight idea as to the trend of work in the field of natural products. Limitations of time and space stood in the way of a more detailed survey. Some very important developments have been omitted because of the difficulty of adequate treatment in a short time.

RESEARCHES ON ORGANIC CHEMISTRY IN INDIA (1896–1923).

By P. C. MITTER, *Ph.D.*, *Palit Professor of Chemistry, Calcutta University.*

(Read at Symposium, September 26-27, 1938.)

Researches on organic chemistry began in India as an offshoot of researches in inorganic chemistry when in 1896 Sir P. C. Ray, who is rightly regarded as the pioneer of chemical research in this country, investigated the action of mercurous nitrite on alkyl halides [1].

There is a gap of ten years between this paper and the next published in 1906, in which Ray and Neogy studied the interaction of alkyl sulphates with the nitrites of the alkali metals [2].

The first chemist to investigate natural products in India was E. G. Hill of Allahabad who with A. P. Sircar published a paper on the colouring matter of *Nyctanthes arbortristis* [3].

Ray and his pupils continued their work on the border-line of inorganic and organic chemistry and in 1910 communicated a paper on the double nitrites of mercury and the bases of the tetra-alkyl-ammonium series [4] and this was followed by numerous similar papers during the succeeding years.

The credit of initiating researches on dyestuffs belongs to E. R. Watson of Dacca College. Watson and Dutt [5] studied the relation between chemical constitution and fastness to light and other agencies of polyhydroxybenzophenones and xanthones, some of which were newly synthesised in this connection. This was followed in 1912 by a similar investigation on some hydroxyketonic dyes [6].

In the same year (1912) Simonsen who had joined the Presidency College, Madras, published, jointly with Cain, a paper on Santalin [7] and in the following year papers on synthesis of unsymmetrical derivatives of desoxybenzoin [8] and derivatives of o-xylene [9] were published by the same author.

The year 1913 was a busy year for Dacca and it saw the publication of papers by Ghosh and Watson on hydroxyquinolphthalein anhydride and hydroxyquinol benzein [10], by Sengupta and Watson on some derivatives of 2: 3: 4: 2′ tetraoxybenzophenone [11], by Sen and Watson on dyes derived from quercetin [12] and by Sircar and Watson on azo-dyes derived from 2-hydroxy-3-naphthoic acid [13]. Watson alone published a paper on 6′-amino quercetin [14] and another on the relation between chemical constitution and the depth of colour of dyes [15].

The laboratory methods of organic chemistry received the attention of Indian chemists and R. L. Datta and his co-workers published a large number of papers on halogenation [16].

VOL. V—No. 2. [Published May 30th, 1939.

The Great War brought in a period of comparative inactivity but in 1915 Medhi and Watson published a paper on the effect of additional auxochrome on the colour of dyes [17].

Simonsen continued his work on syntheses with the aid of monochloromethyl ether, Part III of which was published in 1915 [18], while with Mudlagiri Naik he published a paper on the condensation of ethyl cyano-acetate and acetyl acetone [19], and another on nitration of 3-acetyl-amino-2-methoxy-toluene [20].

From the Bangalore laboratories which Sudborough had joined in the meantime, he published a paper on additive compounds with trinitrobenzene [21] in 1916 and a second paper on the same subject jointly with Cadre [22].

In Dacca, Watson and his school continued their researches on dyes. Dhar, a pupil of Watson, published some researches on xanthone colouring matters [23] and Sircar published a paper on the relation between chemical constitution and colour of azo-dyes [24]. P. C. Ghosh investigated the action of acetaldehyde-ammonia on quinones with a view to prepare organic compounds with two quinonoid arrangements in the molecule [25], while Ghosh and Watson also studied the action of additional auxochromes on the colour of triphenylmethane and azo-dyes [26].

From Bangalore, Sudborough and Lakhumalani published a paper on the displacement of sulphonic acid groups in amino-sulphonic acids by halogen atoms [27].

From the laboratories of the University College of Science, Calcutta, Mitter and Sen contributed a paper on some derivatives of hydrazo- and azo-phthalide [28].

The year 1917 also saw the beginning of the fruitful partnership between Simonsen and Madyar Gopal Rau whose first paper (jointly with Gibson) on the nitration of 2-acetylamino-3 : 4 dimethoxy benzoic acid was published in this year [29]. This was followed by a paper on the nitration of isomeric acetyl-amino-methoxy benzoic acids [30]. In the following year two other papers on the nitration of 5- and 6-acetylamino-3 : 4 dimethoxy benzoic acids and 4-acetylamino veratrole [31] and the bromination of some derivatives of veratrole appeared. Simonsen alone contributed a paper on Morindone [33] and another on the nitration of 2-6-dimethoxy-m-tolualdehyde and m-toluic acids [34].

In the same year, 1918, B. N. Ghosh, who had in the meantime joined the Gauhati College in Assam, published a paper on the synthesis of pyranol derivatives jointly with Chatterji [35]. From Bangalore, Sudborough, Bhagwat and Bhagwat published a paper on alcoholysis [36].

From the Dacca laboratories, Ghosh published a paper on Curcumin [37] in 1919 and also another on dyes derived from quinolinic acid [38].

A second paper on some derivatives of hydrazo- and azo-phthalide [39] was published from the University College of Science, Calcutta, while from the laboratories of the Presidency College which B. B. Dey had joined appeared a paper on ψ-1 : 8 *iso*naphthoxazone [40].

The Gauhati College laboratories were responsible for papers on diketo-hydrindene III [41], condensation of desoxybenzoin with aromatic aldehydes [42], condensation of 1-phenyl 3-methyl 5-pyrazolone with aldehydes and ketones [43] and on condensation of benzoin with diamines [44].

Sudborough and Bhagwat published a paper on the enolisation of carbonyl compounds under the action of the Grignard reagents [45] while Sudborough and Karvé contributed a further paper on alcoholysis [46].

From the College of Science, Calcutta, J. N. Ray published a paper in 1920 on modification and extension of Friedel-Crafts' reaction [47] and another on thianthren in the following year [48].

A new centre of research was started at Ahmedabad from where Meldrum and Alimchandani communicated a paper on the derivatives of gallic acid in 1920 [49] while a second paper appeared in the following year [50].

Simonsen, who had in the meantime joined the Forest Research Institute at Dehra Dun, published a note on the constituents of *Morinda citrifolia* [51] as well as a paper on syntheses with the aid of monochloro-methyl ether, Part IV [52]. These were followed by a paper on the constituents of Indian turpentine from *Pinus longifolia* Roxb., Part I [53] which led to isolation of Δ^3 carene. The following year (1921), Simonsen published a paper on the essential oil from *Andropogon Jwarançusa* Jones and constitution of piperitone [54] and another on the essential oil from the leaves of *Skimmia laureola* [55], besides a paper (with M. G. S. Rau) on the synthesis of 1: 6 dihydroxy 2-methyl anthraquinone [56].

From Dacca, Watson and Dutt communicated a paper on dyes derived from phenanthrenequinone [57] while from Gauhati, Das and Ghosh published a paper on azo-compounds of diketohydrindene [58].

From Bangalore, Sudborough, Picton and Karvé contributed a paper on additive compounds of arylamines with nitro-derivatives of naphthalenes [59] and Sudborough and Karvé on the action of methyl and ethyl alcohols on esters of 2 : 6 dinitro- and 2 : 4 : 6 trinitrobenzoic acids [60] while Sudborough and Dasannacharya communicated a paper on alcoholysis IV [61].

Guha published two papers in 1922, from the College of Science, Calcutta, on the constitution of the so-called dithiourazol of Martin Freund [62, 63], while from the Dacca laboratories, Mukherji published a paper on the colouring matter from 1 : 2 : 4 : 5 tetra-oxy-benzene and related substances [64], Sircar and Dutt on dyes derived from camphoric anhydride [65] and Dutt on dyes derived from phenanthrenequinone [66]. Further, Watson and Dutt contributed two papers on attempts to prepare red sulphide dyes [67, 68].

Indian natural products began to receive the increasing attention of chemists. Simonsen published a paper on the constitution of the terpenes present in the essential oil from *Andropogon Jwarançusa* Jones [69] in which Δ^4 carene was found to be present, another on the essential oil from the leaves of *Abies Pindrow* Spach [70] and a third (with M. G. S. Rau) on the essential oil from *Blumea Malcolmi* [71], while with Rau he published a paper on the constitution of a number of Indian essential oils [72].

The following year (1923), Simonsen published a paper on the essential oil from the gum-oleoresin of *Boswellia serrata* Roxb.[73], on the leaf oil from *Pinus excelsa* and the essential oil from the oleoresin of *Pinus Gerardiana* Wall [74], on the essential oil from the leaves of *Cupressus torulosa* Don [75] and on the constituents of Indian Turpentine from *Pinus longifolia*, Part II [76] and Part III [77].

Watson, Chatterji and Mukherji worked on the odorous and bitter constituents of Neem oil [78].

Rao and Sudborough worked on West Australian sandalwood oil [79] while Desai, Sudborough and Watson investigated Hongay oil from the seeds of *Pongamia Glabra* Vent [80]. Patel, Sudborough and Watson published a paper on cashew kernel oil from the seeds of *Anacardium occidentale* Linn [81].

Further, Advani and Sudborough communicated a paper on the esterification of the cycloparaffin monocarboxylic acids [82], Ayyar and Sudborough worked on the action of bases on $\alpha\alpha\beta$- and $\alpha\beta\beta$-tribromo-β-phenyl propionic acids and their esters [83] while Sudborough and Williams investigated the addition of bromine to α- and β-chloro and bromo-cinnamic acids and their esters [84].

Rao and Iyengar detected the presence of 2-hydroxy-4-methoxy benzaldehyde in the roots of *Decalepsis Hamiltonii* [85].

From Madras, Dey and Row communicated a paper on bromo-nitro-coumarines and their reaction with alkalis [86] and Dey and Dalal on diazo-transformations of amino-coumarines and amino-naphthapyrones [87].

From the College of Science, Calcutta, Sir P. C. Ray, Chakravarti and Bose contributed a paper on the mercaptans of the purine group, Part I [88], Chakravarti on the action of sulphur monochloride on mercaptans [89], Mitter and Bardhan on condensation of amidines with ethoxymethylene derivatives of β-ketonic esters [90] and Guha on ring closures of hydrazine mono-thio- and di-thio-carbamides with acetic anhydride [91].

From the Presidency College, Calcutta, Sircar and Sircar published a paper on phenanthriminazole [92] while Datta published (with Chatterji) his twenty-second paper on halogenation [93].

From the Ahmedabad laboratories, Meldrum and Shah contributed a paper on the action of bromine on p-hydroxy and p-methoxy-sulphonic acids [94] and another on the constitution of sulphosalicylic acids and related substances [95].

Further contributions from the Dacca laboratories during the year 1923 consisted in a paper by Dutt on dyes derived from Diphenic anhydride [96], a paper on peri-naphthindigotin [97] and a third, jointly with Sen, on the action of hydrazine hydrate on phenanthrenequinone [98].

This brings us to the close of the year 1923. The establishment of the Indian Chemical Society with its own organ of publication in the following year, 1924, gave a remarkable fillip to chemical activity in India, so that the Journal of the Indian Chemical Society, which began as a Quarterly Journal, was converted to a monthly publication in 1930.

The first period in the growth of researches in organic chemistry in India which I have attempted to trace in this paper is an admirable record of the progress of a science as the result of whole-hearted co-operation between English and Indian scholars.

REFERENCES.

[1] *Proc. Chem. Soc.*, 1896, 218.
[2] *J.C.S.*, 1906, 1900.
[3] *J.C.S.*, 1907, 1501.
[4] *Proc. Chem. Soc.*, 1910, 172.
[5] *J. Soc. Chem. Ind.*, 1911, **30**, 196.
[6] *J.C.S.*, 1912, 1238.
[7] *J.C.S.*, 1912, 1061.
[8] *J.C.S.*, 1913, 1035.
[9] *J.C.S.*, 1913, 1144.
[10] *Proc. Chem. Soc.*, 1913, 9.
[11] *Proc. Chem. Soc.*, 1913, 269.
[12] *J.C.S.*, 1914, 389.
[13] *J. Soc. Chem. Ind.*, 1913, **32**, 642.
[14] *J.C.S.*, 1914, 338.
[15] *J.C.S.*, 1914, 759.
[16] Houben-Weyl, Vol. III, pp. 803–812.
[17] *J.C.S.*, 1915, 1579.
[18] *J.C.S.*, 1915, 783.
[19] *J.C.S.*, 1915, 792.
[20] *J.C.S.*, 1915, 828.
[21] *J.C.S.*, 1916, 1339.
[22] *J.C.S.*, 1916, 1349.
[23] *J.C.S.*, 1916, 744.
[24] *J.C.S.*, 1916, 757.
[25] *J.C.S.*, 1917, 608.
[26] *J.C.S.*, 1917, 815.
[27] *J.C.S.*, 1917, 41.
[28] *J.C.S.*, 1917, 988.
[29] *J.C.S.*, 1917, 69.
[30] *J.C.S.*, 1917, 220.
[31] *J.C.S.*, 1918, 22.
[32] *J.C.S.*, 1918, 782.
[33] *J.C.S.*, 1918, 776.
[34] *J.C.S.*, 1918, 775.
[35] *J.C.S.*, 1918, 444.
[36] *J. Indian Inst. Sci.*, 1918, **2**, 121.
[37] *J.C.S.*, 1919, 292.
[38] *J.C.S.*, 1919, 1102.
[39] *J.C.S.*, 1919, 1145.
[40] *J.C.S.*, 1919, 531.
[41] *J. Amer. Chem. Soc.*, 1919, **41**, 1221.
[42] *J.C.S.*, 1919, 817.
[43] *Proc. A.S.B.*, 1919, **15**, 132.
[44] *Ibid.*, 1919, **15**, 131.
[45] *J. Indian Inst. Sci.*, 1919, **2**, 187.
[46] *Ibid.*, 1919, **3**, 1.

[47] *J.C.S.*, 1920, 1335.
[48] *J.C.S.*, 1921, 1959.
[49] *J.C.S.*, 1920, 964.
[50] *J.C.S.*, 1921, 201.
[51] *J.C.S.*, 1920, 561.
[52] *J.C.S.*, 1920, 564.
[53] *J.C.S.*, 1920, 570.
[54] *J.C.S.*, 1921, 1664.
[55] *J. Soc. Chem. Ind.*, 1921, **40**, 116.
[56] *J.C.S.*, 1921, 1339.
[57] *J.C.S.*, 1921, 1211.
[58] *J. Amer. Chem. Soc.*, 1921, **43**, 1739.
[59] *J. Indian Inst. Sci.*, 1921, **4**, 43.
[60] *Ibid.*, 1921, **4**, 177.
[61] *Ibid.*, 1921, **4**, 181.
[62] *J. Amer. Chem. Soc.*, 1922, **44**, 1502.
[63] *Ibid.*, 1922, **44**, 1510.
[64] *J.C.S.*, 1922, 545.
[65] *J.C.S.*, 1922, 1283.
[66] *J.C.S.*, 1922, 1944.
[67] *J.C.S.*, 1922, 1939.
[68] *J.C.S.*, 1922, 2414.
[69] *J.C.S.*, 1922, 2292.
[70] *Indian Forest Rec.*, 1922, **8**, 368.
[71] *J.C.S.*, 1922, 876.
[72] *Indian Forest Rec.*, 1922, **9**, 111.
[73] *Ibid.*, 1923, **9**, 289.
[74] *Ibid.*, 1923, **9**, 341.
[75] *Ibid.*, 1923, **10**, 1.
[76] *J.C.S.*, 1923, 549.
[77] *J.C.S.*, 1923, 2642.
[78] *J. Soc. Chem. Ind.*, 1923, **42**, 387.
[79] *J. Indian Inst. Sci.*, 1923, **5**, 163.
[80] *Ibid.*, 1923, **6**, 93.
[81] *Ibid.*, 1923, **6**, 111.
[82] *Ibid.*, 1923, **6**, 41.
[83] *Ibid.*, 1923, **6**, 69.
[84] *Ibid.*, 1923, **5**, 107.
[85] *Perf. Essential Oil Rec.*, 1923, **14**, 300.
[86] *J.C.S.*, 1923, 3375.
[87] *J.C.S.*, 1923, 3384.
[88] *J.C.S.*, 1923, 1957.
[89] *J.C.S.*, 1923, 964.
[90] *J.C.S.*, 1923, 2179.
[91] *J. Amer. Chem. Soc.*, 1923, **45**, 1036.
[92] *J.C.S.*, 1923, 1559.
[93] *J. Amer. Chem. Soc.*, 1923, **45**, 480.
[94] *J.C.S.*, 1923, 1982.
[95] *J.C.S.*, 1923, 1986.
[96] *J.C.S.*, 1923, 225.
[97] *J.C.S.*, 1923, 224.
[98] *J.C.S.*, 1923, 3420.

SYNTHETIC INVESTIGATIONS IN BICYCLIC TERPENES.

By P. C. Guha, D.Sc., *Acting Professor of Organic Chemistry, Indian Institute of Science, Bangalore.*

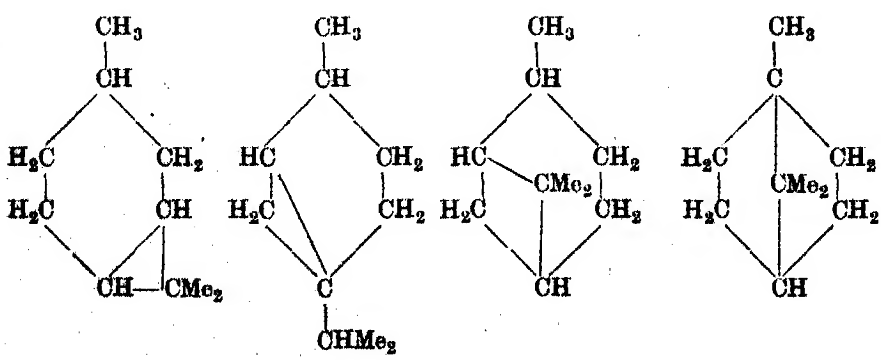
(*Read at Symposium, September 26-27, 1938.*)

Introduction.

Bicyclic ring systems are composed of two rings united directly in the *ortho* position or having more than two carbon atoms common to both rings. The number of possible bicyclic ring systems is large, some are found to exist in naturally occurring terpenes, whilst among the remainder some are known only by synthesis.

Among the constituents of the essential oils, the more important and widely studied are the terpenes and camphors, the former being hydrocarbons of the formula $(C_5H_8)_n$ and the latter their oxygenated products. The bicyclic terpenes, with which we are at present concerned, possess the molecular formula $C_{10}H_{16}$ and differ from one another only in the nature of construction of the two rings, location of the methyl groups and the position occupied by the double bonds.

As a result of the brilliant researches of Bæyer, Bredt, Komppa, Perkin, Ruzicka, Semmler, Wallach, etc., to name only a few amongst others, a large number of compounds belonging to this group have been isolated and their constitutions established by analytical methods and in some cases, particularly in the camphane series, also by synthetic operations. The bicyclic terpenes can be divided into four distinct groups—carane, thujane, pinane and camphane, on the basis as to how the second ring is attached to the *cyclo*hexane ring.

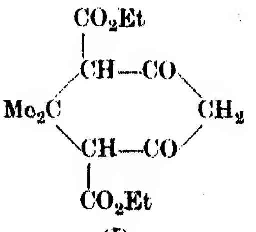


Carane Thujane Pinane Camphane.

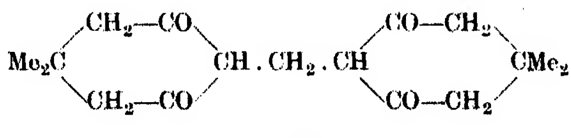
PINANE GROUP.

α-Pinene is the most widely distributed terpene known, being reported to occur in about 420 oils comprising those from all species. Closely related to it is the isomer β-pinene, which has been isolated from about 85 oils. The oxidation products of these terpenes like pinocampheol, pinocamphone, verbenol, verbenone, myrtenol and myrtenal have been found to occur in one or two oils only. The pinenes have a very close genetic relationship with the compounds of the camphane group as camphene, borneol, camphor, which are known to occur fairly widely in Nature.

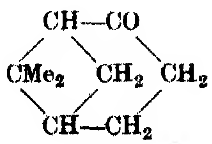
Though the chemistry of the compounds of the pinane group and their derivatives has been fairly thoroughly elucidated, no total synthesis of any bicyclic compound of this group was known when synthetic investigations were launched in this laboratory, the partial synthesis of pinocamphone, α- and δ-pinenes starting from pinonic acid, a direct degradation product of α-pinene, by Ruzicka (*Helv. Chim. Acta.*, 1921, **4**, 666) and the synthesis of norpinic acid by Kerr (*J. Amer. Chem. Soc.*, 1925, **51**, 614) being the only successful synthetic work recorded in literature. Two possible methods open for the synthesis of compounds of this ring system are: (*a*) to start from a *cyclo*hexane compound and effecting bridge formation in 1 : 3 positions through an additional carbon atom, to form a *cyclo*butane ring, or (*b*) to start from a suitable *cyclo*butane derivative and construct the *cyclo*hexane ring with the 1 : 3-carbon atoms. Although the first method has been tried without success by Perkin and Simonsen (*J.C.S.*, 1907, **91**, 1736) and by Stark (*Ber.*, 1912, **45**, 2369), by analogy with the successful bridging of Gaureschi imide with methylene iodide by Kerr (*loc. cit.*), the bridging of Scheiber and Meisel's ester (I) was attempted in this laboratory; but instead of the reaction proceeding as in the case of Kerr's experiment, there was obtained a derivative of methylene bisdimethyldihydroresorcin (II).



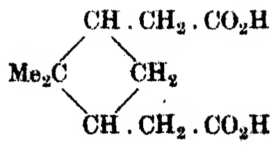
(I)



(II)



(III)



(IV)

The first method having proved unsuccessful, naturally our attention was directed to the second method, viz. synthesis of compounds possessing nopinane

skeleton (bi*cyclo*-1 : 1 : 3-heptane) starting from suitable *cyclo*butane derivatives.

Now that norpinic acid has been synthesized by Kerr (*loc. cit.*) and Guha and Gaind (*J. Ind. Chem. Soc.*, 1934, **11**, 241), the following synthetic investigations have been undertaken starting from norpinic acid: (i) synthesis of ketonopinone and its reduction to nopinone (III); (ii) synthesis of pinocamphone starting from homopinic acid (IV); (iii) synthesis of verbanone from pinononic acid synthesized by us; (iv) synthesis of pinonic acid, which will amount to a total synthesis of α- and δ-pinenes (cf. Ruzicka and Trebler, *Helv. Chim. Acta.*, 1920, **3**, 756; 1921, **4**, 666; 1924, **7**, 489); and (v) synthesis of nopinone, which will amount to a total synthesis of α- and β-pinenes (cf. Wallach, *Annalen*, 1907, **357**, 49; 1908, **363**, 9). The third scheme had to be abandoned in view of the synthesis of verbanone by Komppa and Klami (*Ber.*, 1937, **70**, 788) starting from pinononic acid synthesized in this laboratory.

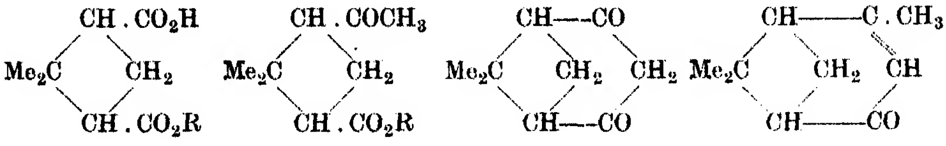
Synthesis of ketonopinone.

Although pinene is very widely distributed in nature and its chemistry very thoroughly elucidated, it is indeed very striking that till now no *total* synthesis of pinene or any of its bicyclic derivatives has been effected. Perkin and Simonsen (*J.C.S.*, 1907, **91**, 1736) have remarked that the synthesis in this series is one of unusual experimental difficulty and it has also been repeatedly observed that the general methods of preparation of six, five and even three-membered rings fail either partly or wholly when applied to *cyclo*butane compounds (Ingold, *J.C.S.*, 1921, **119**, 305, 951, 954). Perkin and Simonsen's (*loc. cit.*) failure to synthesize nopinone, and the fact that Stark's 'demethylated pinone' (*Ber.*, 1912, **45**, 2369) has been proved to be methyl*cyclo*hexenone (Ruzicka, *Helv. Chim. Acta.*, 1920, **3**, 762), seem to justify the above statement. Fortunately, however, there is no strict parallelism between the ease of formation and the stability of the rings in general and that though the *cyclo*butane rings are more difficult to construct, once formed they are quite stable.

The synthesis of bicyclic compounds of the pinene series, by the construction of the *cyclo*butane ring from a *cyclo*hexane derivative by bridging in the 1 : 3-positions, having proved to be not feasible (Guha and Mayurnathan, *J. Indian Inst. Sci.*, 1932, **15**, 131), it was planned to reach the same goal by the reverse process, viz., constructing the *cyclo*hexane ring starting from a suitable *cyclo*butane derivative. This investigation was undertaken with a view to synthesizing pinononic acid (VI, R = H) and nopinone (IV), starting from norpinic acid because, if successful, this was to amount to a total synthesis of pinocamphone, α-, β- and δ-pinenes. Though the final goal has not yet been reached, the syntheses of pinononic acid and 'ketonopinone' (VII) have been achieved. Pinononic acid is a direct degradation product of a number of important naturally occurring substances, having been obtained by Wagner and Ertschikowski (*Ber.*, 1896, **29**, 581) by oxidizing pinene contaminated with

verbenone (VIII) or verbenol and also by direct oxidation of verbenol and verbenone (Guha and Ganapathi, *Ber.*, 1936, **69**, 1185).

Trans-norpinic acid was converted into *cis*-norpinic anhydride which gave the acid ester (V). The acid chloride ester obtained from the acid ester gave, with zinc methyl iodide, methyl pinononate (VI, R = CH), b.p. 130–135°/14 mm., agreeing with that of Wagner and Ertschikowski (*loc. cit.*), and on hydrolysis gave pinononic acid.



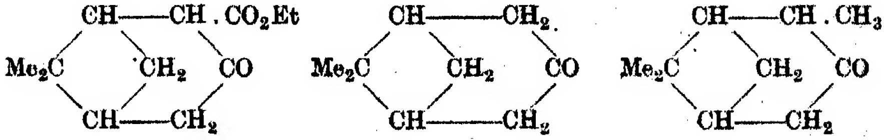
(V) (VI) (VII) (VIII)

Methylpinononate, when heated on the steam bath with sodium in toluene or alcoholic solution, underwent cyclization, giving 'ketonopinone' or 4 : 6-diketonopinane. *It is claimed that this is the first total synthesis of a bicyclic compound in the pinane series.*

The reduction of the diketone (VII) with zinc dust and acetic or hydrochloric acid (cf. Crossley and Renouf, *J.C.S.*, 1907, **91**, 63; 1911, **99**, 1101) or by Clemmensen's method (Khuda, *ibid.*, 1930, 206) has not yielded the desired products, and this may be ascribed to be due to the instability of this β-diketone having the two keto groups directly attached to a *cyclo*butane ring (cf. Simonsen, *The Terpenes*, 1932, Vol. II, 101).

Synthesis of pinocamphone.

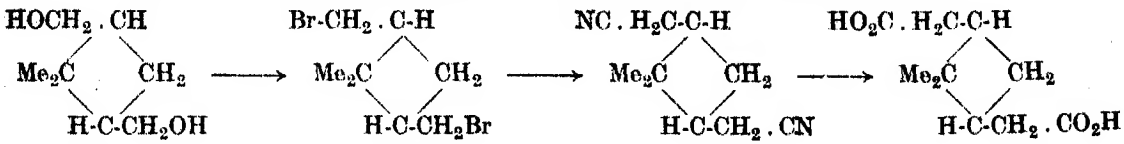
Next, it was planned to synthesize *sym*-homopinic acid (IV) and to cyclize the ester by Dieckmann's reaction to *iso*nopinone-carboxylate (IX) which was expected to yield (*a*) *iso*nopinone (X) by hydrolysis and decarboxylation, and (*b*) pinocamphone by methylation followed by hydrolysis and decarboxylation. The conversion of pinocamphone (XI) into α- and δ-pinenes having already been effected by Ruzicka (*Helv. Chim. Acta.*, 1924, **7**, 489), the synthesis of the former will amount to a total synthesis of α- and δ-pinenes also.



(IX) (X) (XI)

The synthesis of *sym-homopinic acid* starting from *cis*norpinic-diacid-chloride by the action of diazomethane according to the method of Arndt and

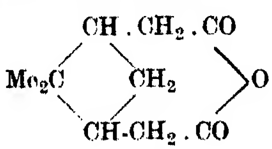
Eistert (*Ber.*, 1935, **68**, 200) did not proceed in the desired manner. The same, however, was achieved starting from diethyl *cis*- or *trans*-norpinate as follows:—



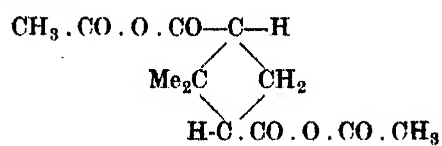
(XII) (XIII) (XIV) (IV)

It is now found that the *cis*- as well as the *trans*-norpinic ester gives on reduction with sodium and alcohol the same *trans*-glycol (XII), which gives *trans*-norpinic acid on oxidation with permanganate. The glycol on treatment with PBr_3 gave the dibromide (XIII), the *trans*-configuration of which has been proved by its conversion back into the *trans*-glycol (XII) on digestion with concentrated barium hydroxide solution. The dibromide with alcoholic sodium cyanide gave the corresponding nitrile (XIV) which on hydrolysis with aqueous potash furnished *sym*-homopinic acid (IV).

The cyclization of this acid to a pinene derivative was tried without success by all the three usual methods. (i) The rule of Blanc (*Comp. rend.*, 1907, **144**, 1356) requires that this acid should not yield the cyclic anhydride (XV) on treatment with acetic anhydride but only the ketone *iso*nopinone (X) if it is of the *cis*-form. It has actually been found that on treatment with acetic anhydride, the acid gives a double anhydride (XVI) similarly as *trans*-*cyclo*butane-1 : 3-dicarboxylic acid which furnishes a similar anhydride (Haworth and Perkin, *J.C.S.*, 1898, **73**, 330).



(XV)

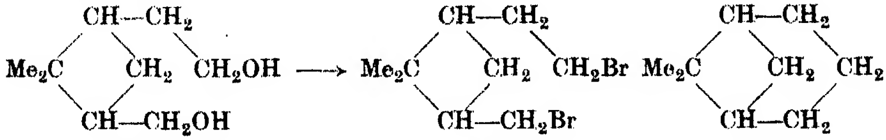


(XVI)

The anhydride (XVI) does not yield any anilic acid, nor any ketone on distillation, but only *trans*-*sym*-homopinic acid on warming with water. (ii) The acid distils unchanged over barium hydroxide (Kandiah, *J.C.S.*, 1931, 922; Barret and Linstead, *ibid.*, 1935, 436) giving rise to no ketone. (iii) The diethyl ester on refluxing for a day with molecular sodium in benzene undergoes no cyclization, but on prolonged boiling in xylene solution gives a trace of a product which does not seem to be the desired compound. It is thus clear that the acid (IV) cannot be cyclized to give rise to a bicyclic compound due to its possessing the *trans*-configuration.

In the light of the results presented above, we are now able to interpret the failure of Ostling (*Oentralblatt*, 1921, **3**, 106; *Overski Finska Ventenskaps Soc.*, 1915, **57A**, No. 23, 14) in obtaining nopinane (XIX) by the action of sodium on the dibromide (XVIII) derived from the glycol (XVII). He seems

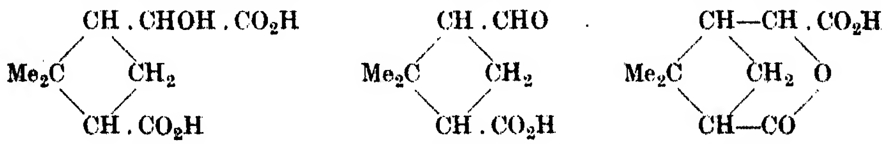
to have assumed the compounds (XVII) and (XVIII) to be of the *cis*-configuration; but, from the results now obtained, it is clear that they possess *trans*-configurations and as such the formation of bicyclic compounds of the pinene group from them is not possible (Guha, Ganapathi, Subramanian and Sankaran, *Ber.*, 1937, **70**, 736).



(XVII) (XVIII) (XIX)

Synthesis and Configuration of Pinic Acid.

The fact that pinic acid, obtained by hypobromite oxidation of *cis*-pinonic acid, is convertible into *cis*-norpinic acid by successive stages through bromopinic acid, hydroxypinic acid (XX), norpinaldehyde (XXI) (Bæyer, *Ber.*, 1896, **29**, 1907; Perkin and Simonsen, *J.C.S.*, 1909, **95**, 1175) led Perkin and Simonsen (*loc. cit.*, Simonsen, *The Terpenes*, Vol. II, p. 128) to suggest that pinic acid as also bromopinic and hydroxypinic acids possess the *cis*-configuration. It occurred to us to be peculiar as to why hydroxypinic acid, in spite of its being a δ-hydroxy acid, is not known to give the lactone (XXII).

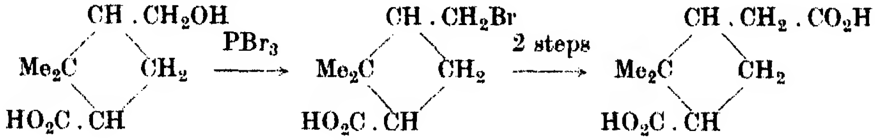


(XX) (XXI) (XXII)

The non-formation of the lactone of hydroxypinic acid was considered as possibly due to its possessing the *trans*-configuration. Since the starting pinonic acid is of the *cis*-form, the change of configuration from *cis* to *trans* can happen in any of the three stages involved in the formation of hydroxypinic acid from pinonic acid. But the change in configuration from *cis* to *trans* seems to be more probable to occur during alkaline oxidation of pinonic to pinic acid, this view receiving further support from the observation of Delepine (*Bull. Soc. Chim.*, 1936, **3**, 1969) that *cis*-pinonic acid is converted into the *trans*-form by means of alkali. Ostling (*Centralblatt*, 1921, **3**, 105) reduced pinic ester with sodium and alcohol and obtained a glycol which has been assigned the *trans*-configuration. Since oxidation of this glycol (XVII) can only yield *trans*-pinic acid (XXIII) it was decided to elucidate the configuration of the pinic acid obtained from pinene via *cis*-pinonic acid, by a comparison of its properties with those of the *trans* acid.

The glycol (XVII), obtained by the reduction of pinic ester, on oxidation with permanganate furnished the pinic acid (XXIII), which in all physical properties resembled that obtained by direct oxidation of pinonic acid.

The acid alcohol (XXIV) obtained by the action of sodium and absolute alcohol on *cis*-norpinic anhydride was proved to be of the *trans*-form, as it yielded *trans*-norpinic acid on oxidation. The acid alcohol was converted into *trans*-pinic acid as follows:



(XXIV) (XXIII)

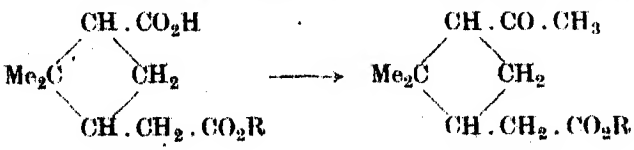
The *trans*-pinic acid thus synthesized resembled the other specimen in all its properties.

Grandperrin (*Annales de Chemie*, 1936, **6**, 26), following another line of argument, has recently suggested that the pinic acid obtained from pinene is of the *trans*-form. Though his conclusion agrees with that of ours, his arguments do not seem to be quite satisfactory.

Having thus proved pinic acid to be of the *trans*-form, experiments are in progress to fix the configuration of hydroxypinic acid and to elucidate at which stage the change-back to the *cis*-form occurs, in the degradation of pinic acid (now proved to be *trans*) to *cis*-norpinic acid (Guha, Ganapathi, Subramanian, *Ber.*, 1937, **70**, 1505).

Attempts to synthesize pinonic acid.

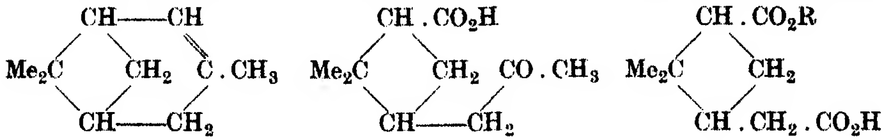
Though the synthesis of *cis*-pinonic acid was not easily feasible, it was, however, thought desirable to synthesize *trans*-pinonic acid (XXVI) and to verify the findings of Delepine (*Bull. Soc. Chim.*, 1935, (5) **3**, 1369) that the liquid variety of pinonic acid obtained from the oxidation of pinene is the *trans*-isomer, also obtainable from the solid *cis*-form by the action of alkali. Since the synthetic pinic acid has been shown to be identical with that obtained by the degradation of α-pinene, we turned to the latter as the most suitable starting material for the synthesis of *trans*-pinonic acid, via the mono-ester (XXV) by Blaise-Mair reaction on its acid chloride. But all attempts to synthesize this acid ester in good quantity were unsuccessful. Attempts were



(XXV) (XXVI)

made to prepare the acid ester (XXV) by partial esterification of pinic acid. By adding just one molecule of alcohol to the di-acid chloride of pinic acid, the yield of the acid ester was found to be very bad (about 5%) the main products being pinic acid and the di-ester.

Fujita (*J. Chem. Soc. Japan*, 1933, **54**, 1811) isolated from the oil of *Orthodon lanceolatum* a hydrocarbon 'orthodene', which on oxidation with permanganate gave a keto-carboxylic acid, $C_{10}H_{16}O_3$, which with alkaline hypobromite has been described to yield, rather curiously, bromonorpinic acid. Since the correctness of the structure (XXVII) for the hydrocarbon depends



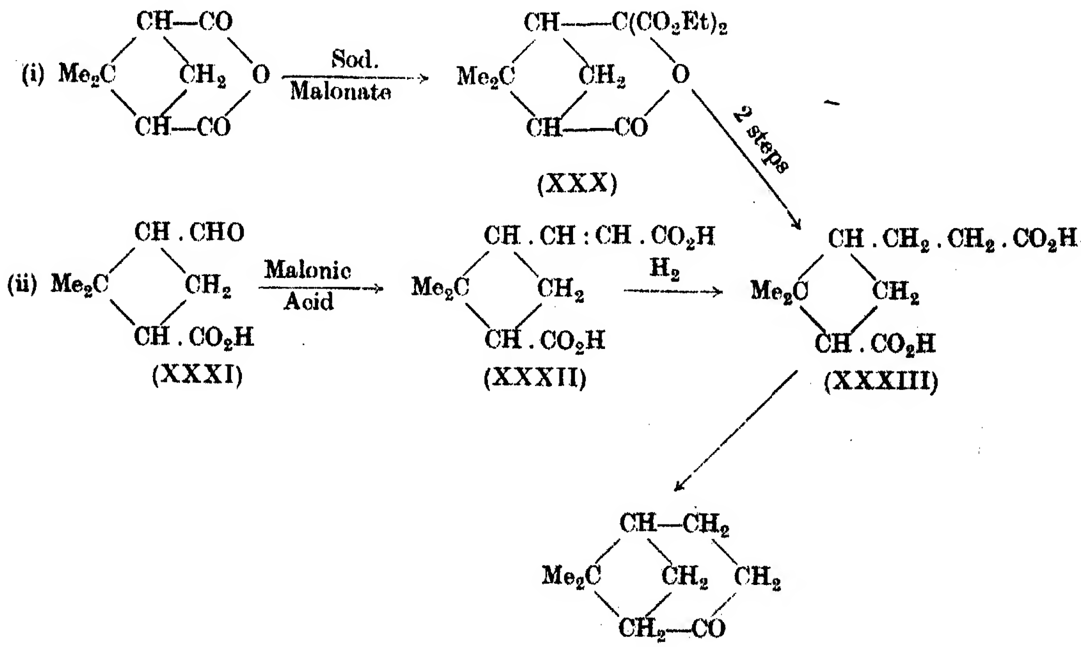
(XXVII) (XXVIII) (XXIX)

entirely on the constitution of the 'keto-carboxylic acid' (XXVIII), we have effected the synthesis of an acid of structure (XXVIII) by the Blaise reaction on the acid chloride of the acid ester (XXIX) obtained in good yield by the partial hydrolysis of pinic ester. The difference of this acid so obtained from *trans*-pinonic acid confirms the structure (XXVIII) assigned to it.

The synthesis of a compound with structure (XXVII) in order to establish its identity with orthodene is in progress.

Nopinone.

The synthesis of nopinone was attempted according to the following two schemes:

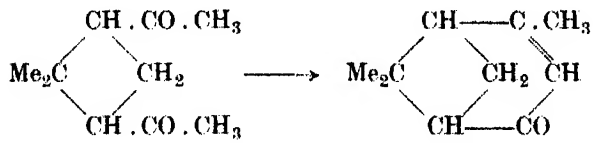


(XXX) (XXXI) (XXXII) (XXXIII) (III)

Since the yield of the compound (XXX) in the first step was very poor, the method had to be abandoned (cf. *Proc. Indian Sci. Cong.*, 1936, p. 190). The synthesis of the acid (XXXIII) was next undertaken starting from norpinic semi-aldehyde (XXXI) obtained by degradation of *trans*-pinic acid synthesized in this laboratory. Though no experimental proof has as yet been obtained as to the stage at which the change of the configuration from *trans* to *cis* takes place in the degradation of *trans*-pinic acid to *cis*-norpinic acid, it appears reasonable that hydroxy-pinic acid, known not to give the lactone, is of the *trans*-form, and norpinic semi-aldehyde is of the *cis*-variety, since the latter gives *cis*-norpinic acid quite readily on oxidation. Norpinic semi-aldehyde condenses with malonic acid to give the desired unsaturated acid (XXXII), which on catalytic reduction gives a saturated acid that appears to be (XXXIII). Work is in progress to secure a sufficient supply of norpinic semi-aldehyde to finish this series of synthetic investigations.

On synthesis of verbenone.

Norpinic di-acidchloride by Blaise reaction under regulated conditions with ZnMeI gave, along with other products, crystallisate, m.p. 103–5°, which appears to be a diketone. Work on the conversion of this into verbenone (VIII) is in progress.



(VIII)

THUJANE GROUP.

The compounds of the thujane group do not occur very widely in Nature. Two hydrocarbons, α-thujene and sabinene, two alcohols, sabinol and thujyl alcohol, and two ketones, thujone and umbellulone, are known and reported to occur in 2, 23, 2, 3, 25 and 1 oil respectively.

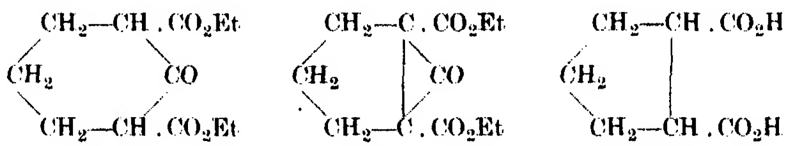
Synthetical experiments in the thujane series are too meagre as compared with the vast amount of work done in the other branches of bicyclic terpenes. The difficulties involved in a successful synthesis of the thujane skeleton lie, not to an inconsiderable extent, in the ease with which the *cyclo*propane ring breaks to give either six or five-membered cyclic compounds depending upon how the ring opens up (cf. Presidential address, Chemistry Section, *Proc. Indian Sci. Cong.*, 1936, p. 148).

For the synthesis of the thujane ring system, there are three possible methods available, viz. to start with a suitable *cyclo*hexane derivative and form the *cyclo*propane ring by direct bridging of the 1 : 3-carbon atoms; to start with a *cyclo*pentane ring and construct the additional *cyclo*propane ring or *vice versa*. The last method has been employed by Ruzicka and Koolhaas

(*Helv. Chem. Acta.*, 1932, **15**, 944) in their partial synthesis of thujane starting from α-thujaketonic acid.

Synthesis of northujane-2 : 6-dicarboxylic ester.

The preparation of compound (I) has been tried by three different methods, viz., (i) by the action of carbonyl bromide upon ethyl pentane-1 : 1 : 5 : 5-tetracarboxylate, (ii) by the treatment of sodium alcoholate on trimethylene dimalonic ester, and (iii) by condensing trimethylene-bromide with ethyl acetonedicarboxylate. Carbonyl bromide reacts readily with tri-methylene dimalonic ester to yield respectively ethyl *cyclo*hexanone-2 : 2 : 6 : 6-tetracarboxylate, which has been converted into *cyclo*hexanone on hydrolysis and decarboxylation. The disodium derivative of (I) reacts with bromine, to yield northujone-2 : 6-dicarboxylic ester. The structure of compound (II) has been definitely established by oxidising it to *cyclo*pentane-1 : 2-dicarboxylic acid (III).



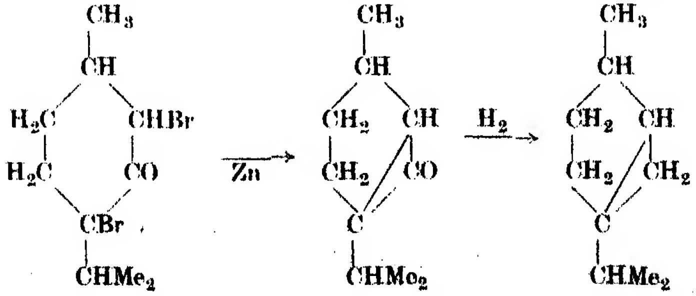
(I) (II) (III)

Trimethylene bromide reacts with the magnesium derivative of ethyl acetonedicarboxylate to yield the keto diester (I). This new method (Guha and Seshadriengar, *Ber.*, 1936, **69**, 1206, 1212) is more convenient to work with and the yield compares favourably with that obtained by the method of Meerwein (*Ann.*, 1913, **398**, 218) from ethyl pentane-1 : 1 : 5 : 5-tetracarboxylate.

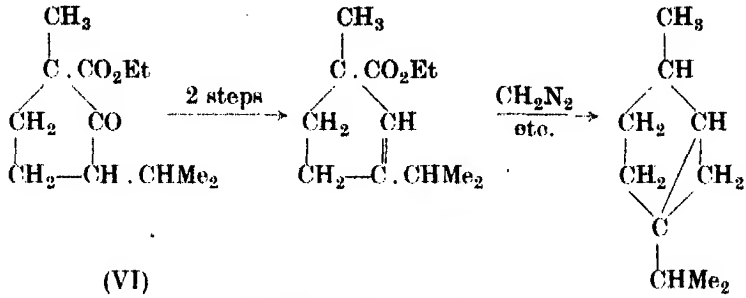
Synthesis of Thujane.

The parent saturated hydrocarbon of this group, thujane (V), has now been synthesized by the first two routes as indicated above, viz. (i) by Guha and Bhola Nath (*Ber.*, 1937, **70**, 931–36) starting from dibromomenthone (IV), and (ii) by Guha and Krishnamurthi (*Ber.*, 1937, **70**, 2112) starting from ethyl-1-methyl-3-*iso*propyl- *cyclo*pentane-2-one-1-carboxylate (VI) as follows:

(i)



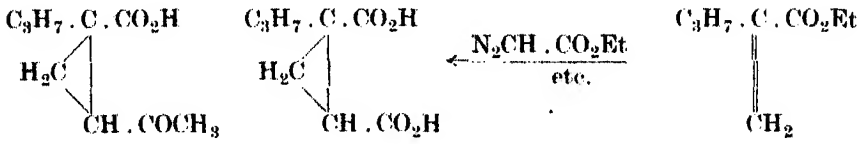
(IV) (V)

(ii) 

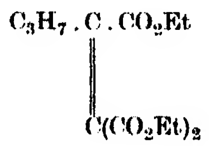
(VI)

Degradation Products.

Many of the naturally occurring compounds of the thujane series yield, on degradation, a series of acids, e.g. umbellularic acid (VII), umbellulonic acid (VI), thujadicarboxylic acid (X) and thujaketonic acid (XI), wherein the *cyclo*-propane ring remains intact. The syntheses of these acids are certainly of great significance since they confirm the presence of the *cyclo*propane ring in compounds of this group. The acid to be synthesized first in this series was umbellularic acid (VII) by Rydon (*J.C.S.*, 1936, 829), by Simonsen (*J.C.S.*, 1936, 828) and also by Ranganathan (*J. Ind. Chem. Soc.*, 1936, **13**, 419), the last having been achieved in this laboratory by the action of diazoacetic ester on ethyl α-*iso*propylacrylate (VIII). This acid (VIII) has also been recently synthesized by Guha and Muthanna (*Current Science*, 1938, **6**, 605) by the action of diazomethane on the unsaturated ester (IX) and hydrolysing the product. It has also been found by Guha and Muthanna (*Current Science*, 1938, **6**, 449) that ethyl α-*iso*propylacrylate (VIII) adds on diazoacetone to yield a pyrazoline derivative which on decomposition furnished umbellulonic acid (VI).



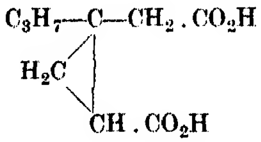
(VI) (VII) (VIII)



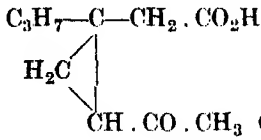
(IX)

Attempts are being made to synthesize thujadicarboxylic acid (X), the anhydride of which has been converted by Guha and Muthanna (work to be published) into thujaketonic acid (XI) by the action of Grignard reagent. The synthesis of the unsaturated ketone (XII), which on addition of diazomethane

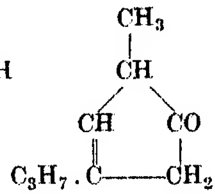
is expected to furnish thujone, is in progress. Work is also in progress to synthesize sabinaketone, β-thujene, isothujone and homothujadicarboxylic acid.



(X)



(XI)



(XII)

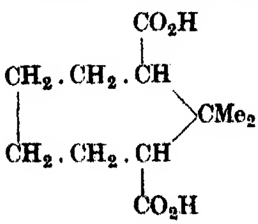
Carane Group.

The three hydrocarbons of this group, viz. Δ^3-, β- Δ^3 and Δ^4 -carenes known till now, do not occur widely in nature. The synthesis of the bicyclic compounds of this group is possible by three methods, viz. (i) starting from a *cyclo*hexane ring and constructing the additional *cyclo*propane ring, or (ii) *vice versa*, and (iii) starting from a *cyclo*heptane ring, to construct the *cyclo*propane ring by direct bridging. All these three methods have been tried in this laboratory.

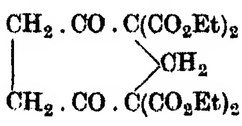
Guha and Sankaran (*Ber.*, 1937, **70**, 1683–1688) have synthesized the *cyclo*heptane acid (I) starting from tetramethylene bromide and Guareschi imide. This acid is expected to be converted into an apocarane derivative by bridging of the carbon atoms carrying the carboxyl groups and decarboxylating the resulting bicyclic compound. The other scheme (Guha and Ghosh) starting from ethyl 4 : 7-diketo*cyclo*heptane-1 : 1 : 3 : 3-tetracarboxylate (II) had to be abandoned since this compound is obtained in small quantities and also offered further difficulties in hydrolysis.

Synthesis of Carane.

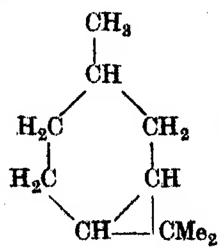
Guha and Sankaran (*Current Science*, 1938, **6**, 606) have succeeded in synthesizing the saturated hydrocarbon, carane (III), by adding dimethyldiazomethane to ethyl Δ^1-tetrahydro-*p*-toluate (IV) and decarboxylating the acid obtained from the resulting bicyclic ester.



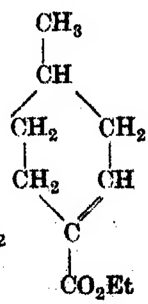
(I)



(II)



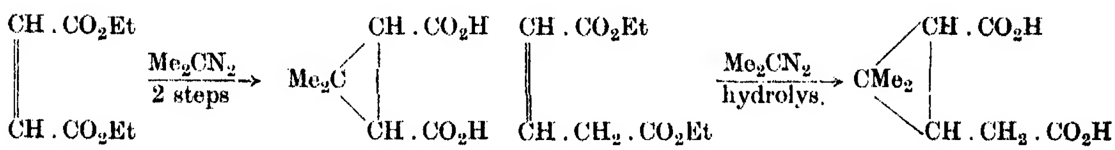
(III)



(IV)

Synthesis of caronic and homocaronic acids.

Some oxidation products of compounds of this group, viz. caronic (V) and homocaronic (VI) acids have been synthesized by Guha and Sankaran (*Ber.*, 1937, **70**, 1688) by the addition of dimethyldiazomethane to ethyl fumarate or maleate and to ethyl glutaconate respectively, as follows:—



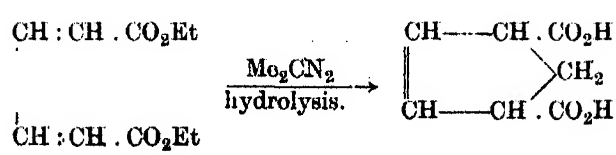
(V) (VI)

CAMPHANE GROUP.

The compounds of this group, viz. camphene, camphor and borneol occur very widely in nature. A vast amount of work has been done in this field perhaps without parallel in any other group of terpenes and not much of synthetic work remains to be done in this group. But there are several degradation products known, the formation of which can only be explained by Wagner and Nametkin rearrangements, characteristic of the members of this group. Hence, it appeared desirable to confirm their constitutions by unequivocal synthesis.

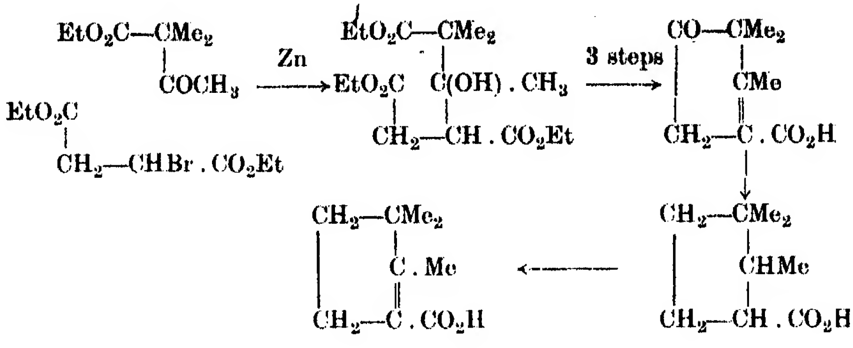
Some important degradation products of camphor.

Isodehydroapocamphoric acid (I) synthesized by Komppa in connection with his synthesis of camphor, through a series of steps starting from $\beta\beta$-dimethylglutaric ester and oxalic ester, has now been synthesized by Guha and Sankaran (*Ber.*, 1937, **70**, 2109) in one step by the addition of dimethyldiazomethane to ethyl muconate.



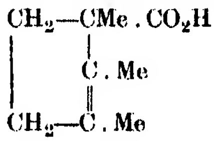
(I)

Isolaurolonic acid was first obtained by Walker (*J.C.S.*, 1893, **63**, 504) by the electrolysis of sodium salt of ethyl hydrogen camphorate. By making use of the Reformatsky synthesis very widely applied in this series, Guha and Subramanian (*Ber.*, 1937, **70**, 228) have succeeded in synthesizing dihydroisolaurolonic acid (II) which has already been converted into isolaurolonic acid (III), as follows:—

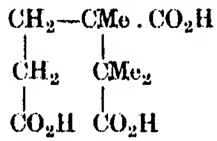


(III) (II)

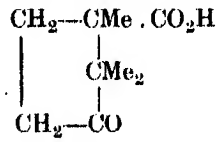
Laurolonic acid (IV) is being synthesized following the procedure indicated above, starting from β-bromobutyric ester and α-methyl-acetoacetate. Similarly, by the action of α-bromo-isobutyric ester on lævulinic ester, homocamphoronic acid (V) has been synthesized which, through camphononic acid (V), is expected to be converted into camphor. It is significant that this synthesis of camphononic acid will amount to a *new* total synthesis of camphor.



(IV)



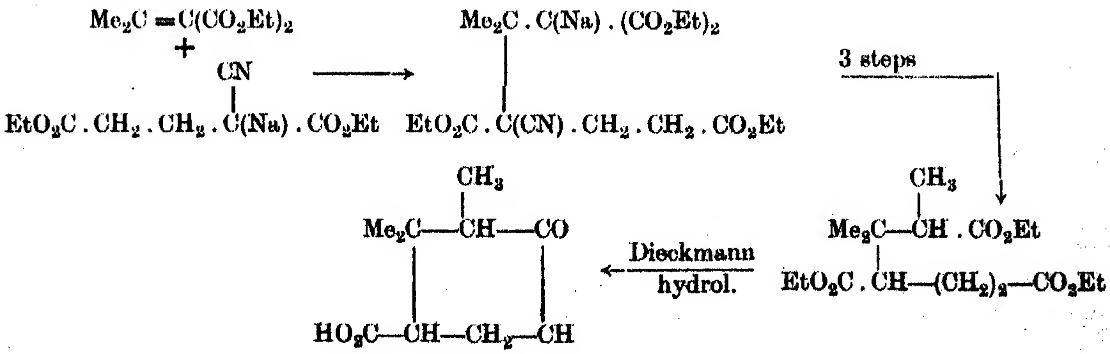
(V)



(VI)

Synthesis of a degradation product of camphorquinone.

To the product obtained from camphorquinone on treatment with sulphuric acid, the formula (VII) is attributed, the formation of this compound involving a peculiar Wagner arrangement. Considerable progress has been made in the synthesis of compound (VII) according to the following scheme:



(VII)

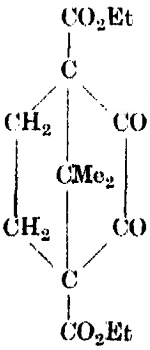
On synthesis of bicyclic compounds of the camphane group.

For this there are only two methods available: (i) to start from a *cyclo*pentane derivative and construct the other ring system, or (ii) to start from a *cyclo*hexane derivative and bridge it in 1 : 4-positions through an additional carbon atom.

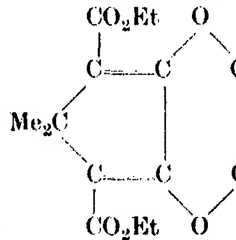
An attempted synthesis of apocamphorquinone.

Although camphorquinone, the interesting bicyclic *o*-diketone, is known and a large number of interesting compounds have been derived from it, it is indeed surprising that its next lower homologue, *apo*camphorquinone is not yet known.

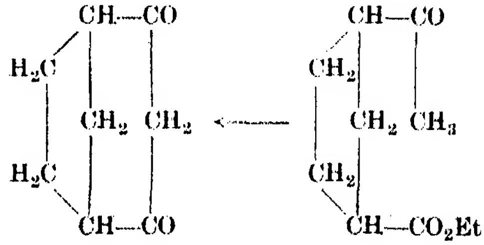
Guha and Ranganathan (*Ber.*, 1936, **69**, 1195) attempted a synthesis of apocamphorquinone by the action of ethylene bromide on the sodium derivative of diketo apocamphoric ester, but the reaction product did not yield the expected diketonic product (VIII), but only the compound (IX). The same authors (*Ber.*, 1937, **69**, 1199) have succeeded, moreover, in synthesizing ketohomonorcamphor (X) starting from the anhydride of *cyclo*pentane-1 : 3-dicarboxylic acid through the ketonic ester (XI).



(VIII)



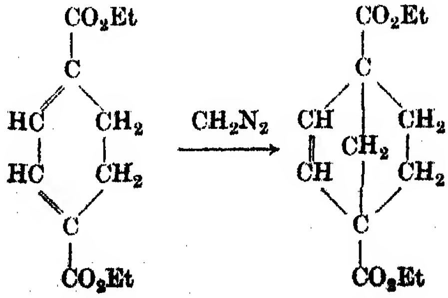
(IX)



(X) (XI)

Action of aliphatic diazo compounds on cyclic conjugated systems.

The synthesis of bicyclic derivatives of the norbornylane group has been attempted by Guha and Hazra by the action of diazomethane on cyclic conjugated systems with the 1 : 4 carbon atoms activated by carbethoxy groups. Thus $\Delta^{1:3}$-dihydroterephthalic ester (XII) has yielded the bicyclic compound (XIII).

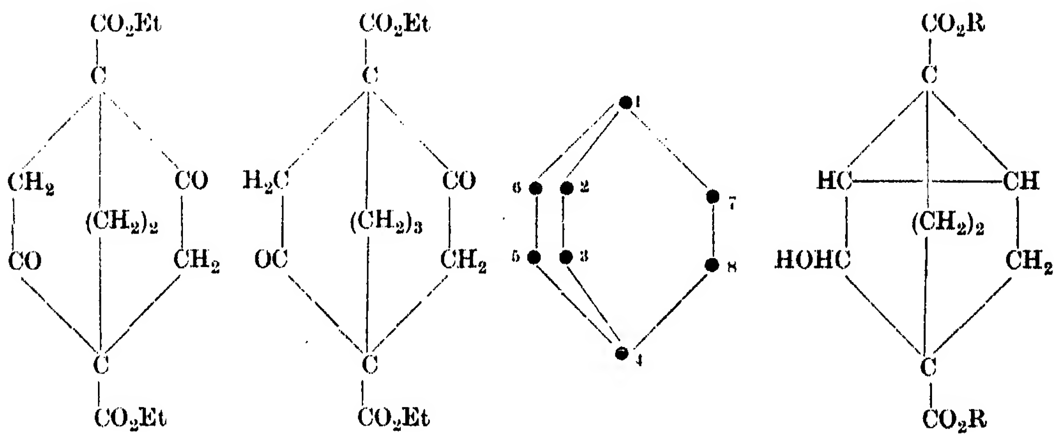


(XII) (XIII)

On synthesis of compounds of the tricyclene type.

Guha (*Current Science*, 1936, **5**, 19) has found that the sodium salt of succinilosuccinic ester, under certain well defined conditions, reacts with ethylene and trimethylene bromides to yield respectively the bicyclic compounds (XIV) and (XV).

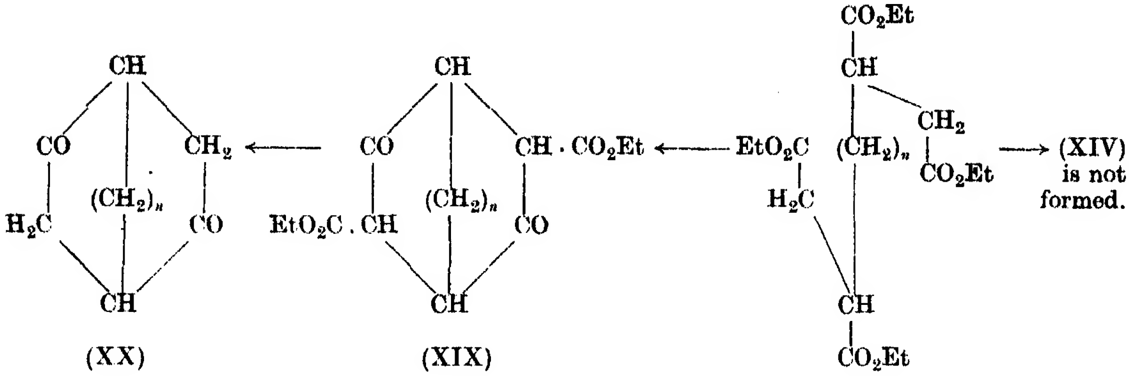
The space model of the parent hydrocarbon *bicyclo*-(2 : 2 : 2)-octane, of which compound (XIV) is only a derivative, is entirely symmetrical about the axis joining the carbon atoms 1 and 4. Further, as the result of this bridging, the keto groups in positions 2 and 5 have come nearer to the methylene groups in positions 6 and 3 respectively (cf. XVI), thus facilitating bridge formation between 2 : 6 and 3 : 5 carbon atoms directly or through the intervention of other carbon atoms. The reduction of the bridged compound (XIV) appears to have yielded such a tricyclic compound (XVII). The results are being confirmed.



(XIV) (XV) (XVI) (XVII)

A new method of synthesis of Bicyclo-(2 : 2 : 2)-octane system.

Another method which is being tried and appears to be of general applicability for the synthesis of bicyclic ring systems is by effecting double ring closure in the ester (XVIII). In one case tried (when $n = 2$), viz. by the action of sodium on $\beta\beta'$-di-carbethoxysuberate, the interesting bicyclic compound (XIX, $n = 2$) has actually been obtained. The corresponding bicyclic diketone (XX), obtained from (XIX) by hydrolysis and decarboxylation, is being converted into the bicyclic hydrocarbon.



(XX) (XIX) (XVIII)

SYNTHESIS OF COUMARINS AND CHROMONES.

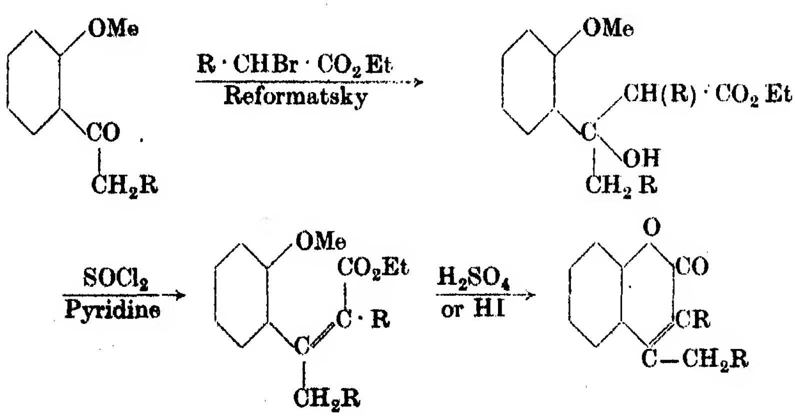
By D. CHAKRAVARTI, *University College of Science and Technology, Calcutta.*

(*Read at Symposium, September 26-27, 1938.*)

The occurrence of a large number of coumarin and chromone derivatives in nature has led many investigators to find out general methods for the synthesis of compounds containing either the benzo-α-pyrone or the benzo-γ-pyrone ring leading to the synthesis of naturally occurring substances. It is proposed to discuss briefly in this paper some of the synthetical methods and their limitations.

The two most important methods for the synthesis of coumarin derivatives are due to Perkin[1] and Pechmann[2]. The naturally occurring coumarins[3] have been obtained either (i) by the closure of the lactonic ring with the necessary substituents in the benzene nucleus, or (ii) by the introduction of the substituents in the requisite coumarin. The action of the sodium salt of an aliphatic acid and its anhydride on an *o*-hydroxy-aldehyde with the intermediate formation of the *o*-hydroxy-cinnamic acid (Perkin's method) and the action of malic acid on phenols in the presence of sulphuric acid (Pechmann's method) have been very convenient methods for the synthesis of naturally occurring coumarins. The *o*-hydroxy-cinnamic acids have also been prepared by other methods and they easily lactonize to coumarins.

Chakravarti and Majumdar[4] have described a method, which bids fair to be a general method for the synthesis of 3 : 4-dialkyl-coumarins not available by the usual methods. *o*-Hydroxy-aryl-alkyl ketones, which are readily available either by Hoesch's reaction or by Fries' rearrangement of acylated phenols, may readily be converted to coumarin derivatives in the following way:



 [Published June 2nd, 1939.

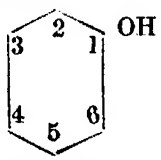
In attempting to synthesize naturally occurring coumarins by this method it has been found by Chakravarti and Majumdar[5] that

(i) When there are two alkyl substituents namely in the α- and β-positions of the expected cinnamic acid, *cis*-cinnamic acid is formed and the coumarin is obtained in quantitative yield.

(ii) When there is no substituent in the α- and β-positions or when there is only one substituent in the α-position of the expected cinnamic acid, *trans*-cinnamic acid (*i.e.*, *o*-coumaric acid) is formed and ring-closure does not take place forming coumarin.

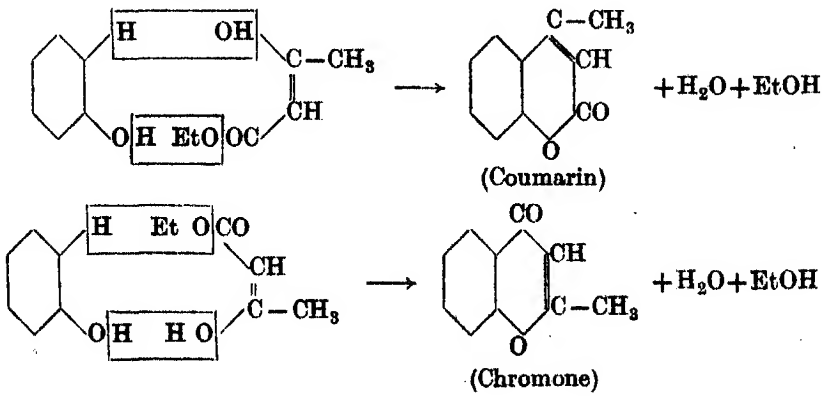
Thus this synthetical method may also be utilized for obtaining *o*-coumaric acids readily in quantity.

Pechmann *et al*[6] prepared various coumarin derivatives with alkyl substituents in the pyrone ring by the condensation of a phenol with a β-ketonic ester in the presence of sulphuric acid as the condensing agent. In Pechmann's reaction for the synthesis of coumarins Clayton[7] found that different phenols condense with varying degree of readiness and the reaction is always facilitated by the presence of a hydroxyl or an alkyl group in position 3, position 6 being occupied by the carbon atom taking part in the condensation.



Though the presence of a halogen atom in the phenolic nucleus greatly hinders Pechmann's reaction a substituent like nitro or carboxyl group totally inhibits the reaction; but a phenol like resorcinol, which has the faculty of forming a coumarin with great readiness, reacts readily with acetoacetic ester even if there be a halogen atom or a nitro or a carboxyl group in the phenolic nucleus[8].

The condensation of a phenol with a β-ketonic ester may lead to two different products either a coumarin or a chromone:



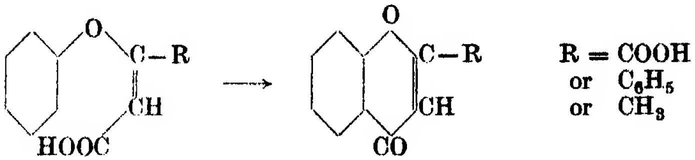
Pechmann[6] showed that coumarins are obtained by using sulphuric acid as the condensing agent and Simonis[9] showed that chromones are obtained by using phosphorus pentoxide. These two reactions have been extensively studied by Chakravarti and co-workers[10, 8] and Robertson and others[11] with special reference to the part played by the condensing agent and the influence of any substituent in the molecule of the β-ketonic ester or the phenol. The generalization made by Chakravarti[12] that "those phenols which readily give coumarins with β-ketonic esters in the presence of sulphuric acid also give coumarins and not chromones in the presence of phosphorus pentoxide and those phenols which give coumarins with sulphuric acid in poor yield or do not react at all, produce good yields of chromones", has been supported by numerous experimental facts and it has also been shown by Chakravarti *et al*[10, 8] that the chromone condensation could be facilitated by the introduction of halogen and nitro groups into the molecules of those phenols which do not satisfactorily respond to Pechmann's reaction, specially in the case of the monohydric phenols.

The halogen and nitro groups exert an inhibiting effect in Pechmann's reaction in the formation of coumarins and a favourable influence in chromone formation in Simonis' reaction. It is noteworthy that neutral, basic or acidic condensing agents like sodium acetate, sodium ethoxide, hydrochloric acid, boric anhydride, zinc chloride, phosphoric acid, aluminium chloride, etc., bring about coumarin condensation[13] and the behaviour of phosphorus pentoxide is remarkable. Goodall and Robertson[14] have found that phosphoryl chloride in some cases brings about chromone condensation.

If there is condensation under Pechmann's condition coumarins are invariably formed. β-Naphthol is the only phenol which has been found by Dey and Lakshminarayanan[15] to give a mixture of coumarin and chromone by Pechmann's reaction (only with unsubstituted acetoacetic ester). With alkyl-acetoacetic ester, however, β-naphthol condenses in the presence of sulphuric acid to form a coumarin and not a chromone.[16]

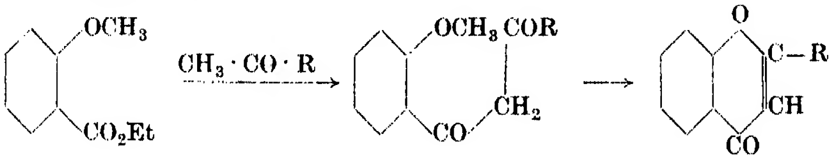
A large volume of work has been done on chromones and quite a number of methods is available for synthesizing derivatives of chromones and chromonols. Chromones, on hydrolysis with different hydrolytic agents, break up into phenols, *o*-hydroxy-acetophenones and *o*-hydroxy-acids, and methods have been developed to build up the chromones from any one of these fission products but some of these methods form along with the γ-pyrones the α-pyrones.

The phenols have been used by Ruhemann[17] and Simonis[9] for the synthesis of chromone derivatives. Ruhemann condensed sodium phenolates with ethyl chloro-fumarate, ethyl phenyl-propiolate and ethyl β-chloro-crotonate and treated the intermediate products, thus obtained, with concentrated sulphuric acid or better with phosphorus pentachloride and aluminium chloride whereby the desired chromones were obtained:



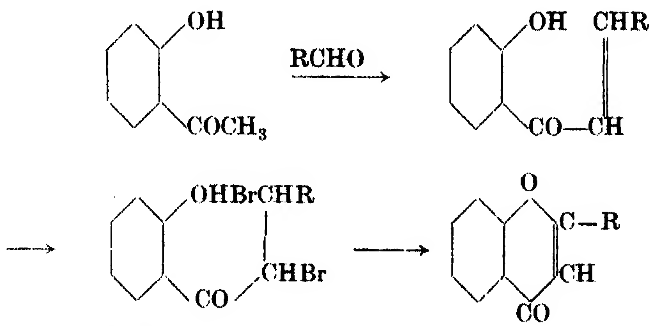
With ethyl phenyl-propiolate the yield was satisfactory but with the other two the yields were far from being so. Simonis' method is a modification of Pechmann's method from phenols and β-ketonic esters, but in this reaction α-pyrones are also formed and it has a very limited applicability (*vide supra*).

The only attempt at synthesizing chromones from *o*-hydroxy-acid was made by Kostanecki[18] who condensed ethyl *o*-methoxy-benzoate with acetone and acetophenone and obtained the chromones on heating the intermediate β-diketones with hydriodic acid:

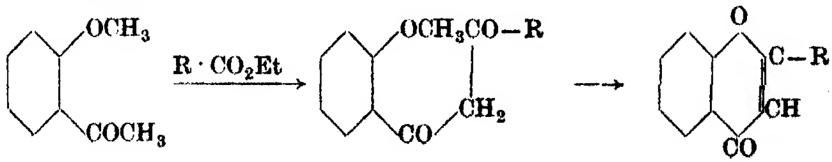


The *o*-hydroxy-acetophenones have been largely used for the synthesis of chromone derivatives:

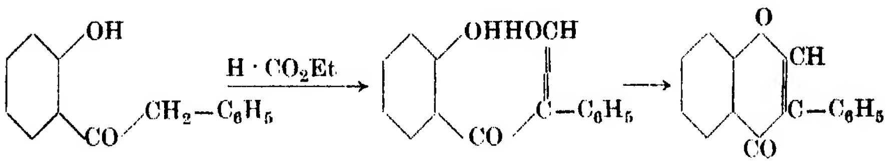
(i) Kostanecki[19] condensed *o*-hydroxy-acetophenones with aldehydes giving rise to chalkones, the dibromides of which on treatment with alkali form chromones.



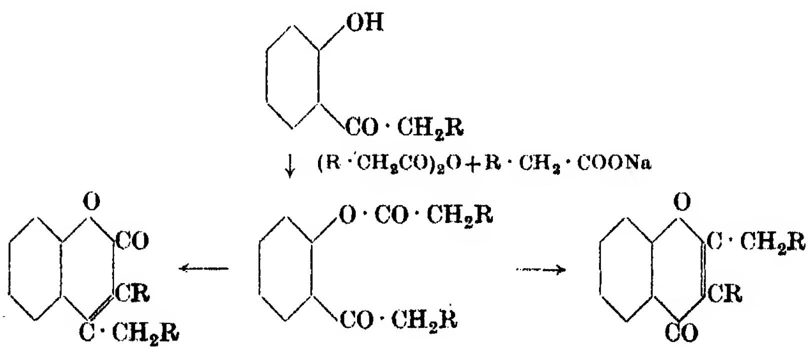
(ii) Kostanecki[20] condensed esters with *o*-methoxy-acetophenones and from the intermediate β-diketones formed chromones were obtained on boiling with hydriodic acid.



(iii) Späth[21] condensed *o*-hydroxy-phenyl-benzyl-ketones with ethyl formate and the intermediate oxy-methylene ketones gave *iso*flavones on ring closure with hydrochloric acid. This method has been modified by Mahal, Rai and Venkataraman[22].



(iv) Nagai[23] and Tahara[24] heated resacetophenone and pænol with sodium acetate and acetic anhydride and obtained compounds which were shown by Kostanecki and Rozyoki[25] to be derivatives of chromones. This very convenient method has been further developed by Robinson[26] and used by him in synthesizing a large number of chromones and chromonols occurring in nature by heating various *o*-hydroxy-aryl-ketones with the anhydrides and the corresponding sodium salts of aliphatic and aromatic acids. Recent researches[27], however, have shown that the method is not of general applicability, inasmuch as chromones or coumarins or a mixture of them may result from the above reaction, since there are two ways in which the intermediate acyl derivative may lose the elements of water giving a chromone or a coumarin:



(Coumarin) (Chromone)

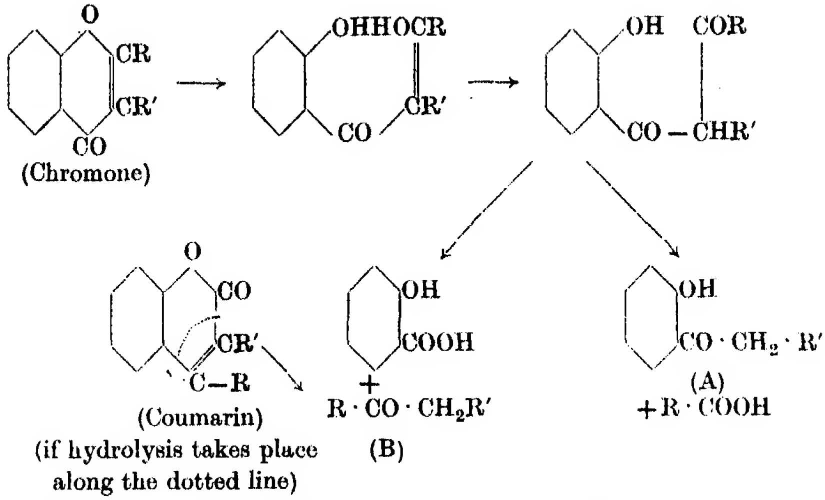
Heilbron and co-workers[28] have found that the nature of the product in this reaction depends on (i) the nature of the *o*-hydroxy-ketone and (ii) the acid anhydride and the salt used. The following Table summarizes the experimental facts regarding the formation of coumarins and chromones by the application of Kostanecki's reaction.

Ketone used.	Acid anhydride used.	Product obtained.
o-Hydroxy-acetophenone	Acetic anhydride +Sodium acetate.	Chromone (sometimes with traces of coumarin.)
o-Hydroxy-acetophenone	Propionic anhydride +Sodium propionate.	Coumarin.
o-Hydroxy-propiophenone	Acetic anhydride +Sodium acetate.	Chromone.
o-Hydroxy-propiophenone	Propionic anhydride +Sodium propionate.	Chromone.
o-Hydroxy-propiophenone	Butyric anhydride +Sodium butyrate.	Chromone.
o-Hydroxy-acetophenone	Phenylacetic anhydride +Sodium phenylacetate.	Coumarin.
o-Hydroxy-propiophenone	,, ,, ,,	Coumarin.

Hence Heilbron and co-workers conclude[29] 'In each case it is the hydrogen of the reactive methylene group between phenyl and carbonyl which takes part in the ring closure. This influence is sufficiently powerful to outweigh the weaker effects introduced either by replacing the methyl ketone by the ethyl ketone or by using derivatives of propionic acid in place of those of acetic acid. The influence of the phenyl group on the course of the Kostanecki's reaction, though more powerful, is in the same direction as that of the methyl group. When substituted in the sodium salt and the acid anhydride both groups favour coumarin formation, but when substituted in the hydroxy-acetophenone side chain both groups favour chromone formation.'

The above generalization of Heilbron has also been supported by the work of Flynn and Robertson [30] and of Chakravarti and Bagchi [31]. Chakravarti and Majumdar [32] have further shown by a detailed study of Kostanecki's reaction on the halogenated aceto-, propio-, and butyro-phenones that the halogen atom has no marked influence towards the formation of γ-pyrones as in Simonis' reaction (*vide supra*).

It has often been a puzzle for the investigators in this line to distinguish whether a compound is an α-pyrone or a γ-pyrone derivative and absolute reliance on the hydrolytic method has often misled workers to assign a γ-pyrone structure to a compound having an α-pyrone structure.[33] According to Baker [34] the only safe criterion of a chromone structure is the formation on hydrolysis of a hydroxy-ketone of the type (A). The formation of a neutral ketone of the type (B) is also possible for an isomeric coumarin:



On treatment with alkali the lactonic ring of the coumarin breaks up and it is difficult to isolate the coumarinic acid thus formed as it easily lactonizes forming the original coumarin unless the coumarinic acid changes to *o*-coumaric acid (*vide* Sen and Chakravarti [35]). Canter and Robertson [36] have found out a convenient method for distinguishing the coumarins by methylating the *o*-hydroxy-cinnamic acid, thus formed, and isolating *o*-methoxy-cinnamic acid. This method has been very helpful to distinguish a coumarin from an isomeric chromone.

The reactivity of the 2-methyl group in 2-methyl-chromones (*cf.* Heilbron, Barnes and Morton [37]) has been taken advantage of by Chakravarti [10] to distinguish the 2-methyl-chromones, which easily form styryl derivatives by condensation with aromatic aldehydes in the presence of alcoholic sodium ethoxide. The reactivity of the 2-methyl group is not in any way influenced by the presence of a group in the benzene nucleus particularly in position 7. Similarly the 2-ethyl-chromones have also been found to form styryl derivatives though rather slowly by Heilbron, Hey and Lowe, [38] but in certain cases it has not been possible to prepare 2-styryl derivatives from authentic 2-ethyl-chromones (Chakravarti and Majumdar [32]).

Wittig [39] developed a method for the separation of the coumarins from the chromones. This method is based on the fact that by the action of alcoholic sodium ethoxide on a coumarin, the lactonic ring breaks up and the coumarin is regenerated on acidification, whereas in the case of a chromone, the pyrone ring opens with the formation of a diketone, which forms the chromone only on heating with sulphuric acid or acetic acid. Though this method has often been used (Heilbron, Hey and Lythgoe [40]), Chakravarti and Majumdar [32] have come across irregularities in the course of this reaction. Some authentic coumarins, *e.g.* coumarin itself, on keeping overnight with alcoholic sodium ethoxide, give on acidification along with the original coumarin a large

proportion (about 50%) of *o*-coumaric acid. Again chromones on treatment with alcoholic sodium ethoxide give in some instances the *o*-hydroxy-ketone by the further hydrolysis of the diketone formed [32].

REFERENCES.

1 Perkin, *J. Chem. Soc.*, 1868, **21**, 53 *et seq.*
2 Pechmann, *Ber.*, 1884, **17**, 929; Pechmann and Welsh, *ibid.*, p. 1646.
3 Späth, *ibid.*, 1937, **70**, 83.
4 Chakravarti and Majumdar, *J. Indian Chem. Soc.*, 1938, **15**, 136.
5 Chakravarti and Majumdar, *Science and Culture*, 1938, **4**, 64.
6 Pechmann *et al*, *Ber.*, 1883, **16**, 2119 *et seq.*
7 Clayton, *J. Chem. Soc.*, 1908, **93**, 2018.
8 Chakravarti and Ghosh, *J. Indian Chem. Soc.*, 1935, **12**, 622, 791; Chakravarti and Banerjee, *ibid.*, 1936, **13**, 619; 1937, **14**, 37; Chakravarti and Bagchi, *ibid.*, 1936, **13**, 649; Shah, Sethna, Banerjee and Chakravarti, *ibid.*, 1937, **14**, 717; Chakravarti and Mukherjee, *ibid.*, 1937, **14**, 726.
9 Simonis *et al*, *Ber.*, 1913, **46**, 2015; 1914, **47**, 697, 2229.
10 Chakravarti, *J. Indian Chem. Soc.*, 1931, **8**, 130, 407; 1932, **9**, 25, 31, 389.
11 Robertson *et al.*, *J. Chem. Soc.*, 1931, 2426; 1932, 1180, 1681; 1936, 215.
12 Chakravarti, *J. Indian Chem. Soc.*, 1932, **9**, 31.
13 Chakravarti, *ibid.*, 1935, **12**, 536; Appel, *J. Chem. Soc.*, 1935, 1031; Sethna, Shah and Shah, *ibid.*, 1938, 228, 1066. *Cf.* also Naik, Desai and Desai, *J. Indian Chem. Soc.*, 1929, **6**, 801; Desai and Hamid, *Proc. Ind. Acad. Sci.*, 1937, **6**, 185.
14 Goodall and Robertson, *J. Chem. Soc.*, 1936, 426.
15 Dey and Lakshminarayanan, *J. Indian Chem. Soc.*, 1932, **9**, 153.
16 Chakravarti, *ibid.*, 1932, **9**, 389.
17 Ruhemann *et al*, *J. Chem. Soc.*, 1900, **77**, 1185, etc.; *Ber.*, 1913, **46**, 2188; 1920, **53**, 285.
18 Kostanecki, *Ber.*, 1903, **33**, 32, 1998.
19 Kostanecki, *ibid.*, 1898, **31**, 696 *et seq.*
20 Kostanecki, *ibid.*, 1900, **33**, 471 *et seq.*
21 Späth and Lederer, *ibid.*, 1930, **63**, 743.
22 Mahal, Rai and Venkataraman, *J. Chem. Soc.*, 1934, 1770.
23 Nagai, *Ber.*, 1892, **25**, 1284.
24 Tahara, *ibid.*, 1892, **25**, 1292.
25 Kostanecki and Rozycki, *ibid.*, 1901, **34**, 102.
26 Allan and Robinson, *J. Chem. Soc.*, 1924, **125**, 2192.
27 Wittig, Baugert and Richter, *Annalen*, 1925, **446**, 155; Bargellini, *Atti. R. Accad. Lincei*, 1925, **2**, 261; Chadha, Mahal and Venkataraman, *J. Chem. Soc.*, 1933, 1460; Baker and Eastwood, *ibid.*, 1929, 2906.
28 Heilbron and co-workers, *J. Chem. Soc.*, 1933, 1263; 1934, 1311, 1581; 1936, 295.
29 Heilbron, Hey and Lythgoe, *ibid.*, 1936, 295.
30 Flynn and Robertson, *ibid.*, 1936, 215.
31 Chakravarti and Bagchi, *J. Indian Chem. Soc.*, 1936, **13**, 689.
32 Chakravarti and Majumdar, *unpublished work.*
33 Kelkar, *Rasayanam*, 1936, **1**, 68.
34 Baker, *J. Chem. Soc.*, 1925, 127, 2351.
35 Sen and Chakravarti, *J. Indian Chem. Soc.*, 1930, **7**, 247; Chakravarti, *ibid.*, 1931, **8**, 391.
36 Canter and Robertson, *J. Chem. Soc.*, 1931, 1875.
37 Heilbron, Barnes and Morton, *ibid.*, 1923, **123**, 2569.
38 Heilbron, Hey and Lowe, *ibid.*, 1934, 1311.
39 Wittig, *Ber.*, 1924, **57**, 88.
40 Heilbron, Hey and Lythgoe, *J. Chem. Soc.*, 1934, 1581.

NEW SYNTHETICAL METHODS IN COUMARIN CHEMISTRY.

By R. C. SHAH.

(*Read at Symposium, September 26-27, 1938.*)

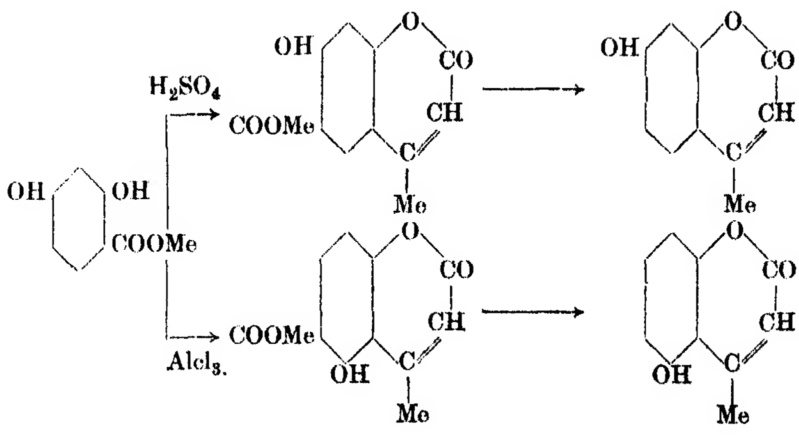
A variety of coumarin derivatives have been synthesized by new methods developed in these laboratories. A number of coumarins, particularly 5-hydroxycoumarins, which are of synthetical importance and have been hitherto inaccessible or accessible only with great difficulty, are thus made readily available.

Of the various synthetical methods available for the synthesis of coumarins that of Pechmann and Duisberg (*Ber.*, 1883, *16*, 2119), which consists in the condensation of a B-ketonic ester with a phenol, is one of the more important and has been most widely used. The principal condensing agents which have been hitherto used have been concentrated sulphuric acid (Pechmann Reaction ; *Ber.*, 1883, *16*, 2119) and phosphoric anhydride (Simonis Reaction; *Ber.*, 1913, *46*, 2015), the product being either a coumarin or a chromone or rarely a mixture of both, depending on the nature of the ester, the phenol, and the condensing agent. It is now generally accepted that more reactive phenols give coumarins with both the condensing agents, whereas less reactive phenols, which either do not react at all or give only poor yields of coumarins in presence of sulphuric acid, tend to give chromones with phosphoric anhydride (Chakrawarti, *J. Ind. Chem. Soc.*, 1932, *9*, 31). A number of other condensing agents, like zinc chloride, hydrogen chloride, phosphoryl chloride, phosphoric acid, and sodium ethoxide have been also occasionally used, with results of no particular interest, the same products as those with sulphuric acid being obtained in varying yields (Naik, Desai and Desai, *J. Ind. Chem. Soc.*, 1929, *6*, 801; Chakravarti, *ibid.*, 1935, *12*, 536; Appel, *J.C.S.*, 1935, 1031). Phosphoryl chloride however promises to be of interest as it can replace phosphoric oxide in some cases (Goodall and Robertson, *J.C.S.*, 1936, 426) and has been found to be valuable for the condensation of polyhydroxy-phenolic ketones with B-ketonic esters (Desai and Hamid, *Proc. Ind. Acad. Sci.*, 1937, *6*, 185).

The condensation of B-ketonic esters with phenols in the presence of anhydrous aluminium chloride, a new reagent for this purpose, has been studied in these laboratories for some time, and from the results obtained, which are unique in some respects, it promises to be a valuable reagent. The condensation is generally carried out in the presence of a solvent-ether in which aluminium chloride dissolves readily (Shah, *Current Science*, 1934, 157) or in nitrobenzene where elevated temperatures have to be used.

1. *Simple phenols.*—The same products are obtained as with sulphuric acid, in some cases with higher yields. In no case has a chromone been obtained. The reagent is of particular value in the case of the little reactive monohydric phenols. Phenol uniformly gives a yield of 30–40% of 4-methylcoumarin, the recorded yield in literature using sulphuric acid being only 3% (Sethna, Shah and Shah, *Current Science*, 1937, *3*, 93). O-cresol, which does not condense using sulphuric acid, readily condenses with ethyl acetoacetate giving 4 : 8-dimethyl-coumarin.

2. *Phenolic esters.*—Methyl B-resorcylate condenses with ethyl acetoacetate in the presence of sulphuric acid giving methyl 7-hydroxy-4-methyl-coumarin-6-carboxylate (Shah *et al*, *J. Ind. Chem. Soc.*, 1937, *12*, 717). The same condensation in the presence of aluminium chloride affords mainly methyl 5-hydroxy-4-methyl-coumarin-6-carboxylate, from which by hydrolysis and subsequent decarboxylation, 4-methyl-5-hydroxy-coumarin is readily obtained (Sethna, Shah and Shah, *J.C.S.*, 1938, 228). Limaye previously obtained 4-methyl-5-hydroxy coumarin in a minute yield as a bye-product in the Kostanecki acetylation of 2-acetylresorcinol, the main product being 5-hydroxy-2-methyl-chromone (Limaye and Kelkar, *Rasayanam*, 1936, 45). Methyl 2 : 4-dihydroxy-5-ethyl-benzoate similarly gives methyl 5-hydroxy-4-methyl-8-ethyl-coumarin-6-carboxylate from which 5-hydroxy-4-methyl-8-ethyl coumarin has been obtained (Sethna and Shah, *J.C.S.*, 1938, 1066). The work is being extended to α-chloro, and α-alkyl-, acetoacetic esters, and benzoylacetic and acetone dicarboxylic esters on the one hand, and other phenolic esters on the other.

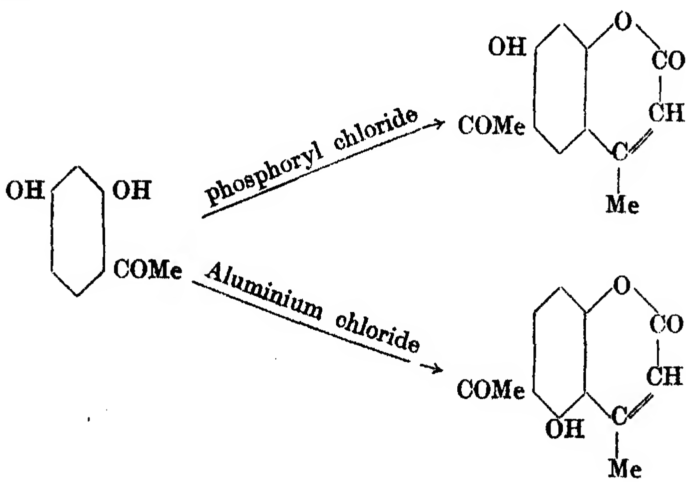


3. *Phenolic ketones.*—Resacetophenone does not condense with ethyl-aceto-acetate in the presence of sulphuric acid or sodium ethoxide contrary to the statement of Aggrawal and Dutt (*J. Ind. Chem. Soc.*, 1937, *14*, 109). The condensation takes place readily in the presence of aluminium chloride, the product obtained in high yield being proved to have the constitution of

5-hydroxy-4-methyl-6-acetyl coumarin (Sethna, Shah and Shah, *loc. cit.*). Orsacetophenone and 2: 4-dihydroxy-benzophenone react similarly giving the corresponding 5-hydroxy-coumarin derivatives, 5-hydroxy-6-acetyl-4 : 7-dimethyl-coumarin and 5-hydroxy-6-benzoyl-4-methyl-coumarin respectively. Phloracetophenone gives an acetyl coumarin, which may have the constitution of 5:7-dihydroxy-4-methyl-6-acetyl-coumarin or 5: 7-dihydroxy-4-methyl-8-acetyl-coumarin; the latter constitution is more likely as it can be completely methylated easily. 2-Acetyl resorcinol gives 7-hydroxy-8-acetyl-coumarin in better yield than with sulphuric acid. O-hydroxy-acetophenone, quinacetophenone and gallacetophenone do not react (N. M. Shah and R. C. Shah, *J.C.S.* 1939, 1424.)

In this connection it is worthy of note that although resacetophenone does not condense with B-ketonic ĕsters in the presence of sulphuric acid, Desai and Hamid (*loc. cit.*) find that the condensation takes place readily in the presence of phosphoryl chloride, the products being 7-hydroxy-6-acetyl-coumarins.

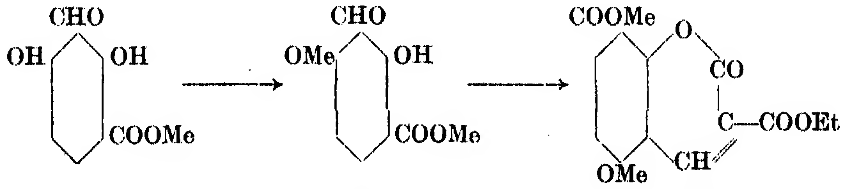
Thus the main points of interest with regard to the use of the new reagent are: (1) With less reactive phenols like monohydric phenols, aluminium chloride is a much more efficient condensing agent than sulphuric acid. (2) With phenolic esters and phenolic ketones, 5-hydroxy coumarin derivatives, which are otherwise difficultly accessible, are easily obtained, the other condensing agents like sulphuric acid or phosphoryl chloride giving 7-hydroxy-coumarin derivatives.



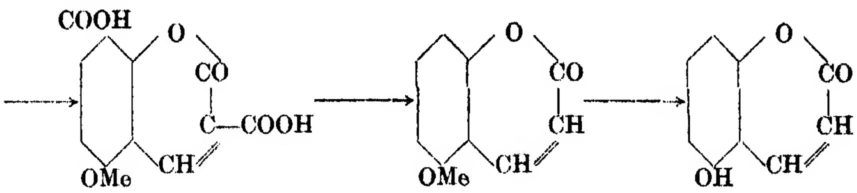
The Gattermann reaction on phenolic esters has provided another route to interesting coumarin derivatives. Methyl B-resorcylate does not undergo the Gattermann reaction under the usual conditions, but under the modified conditions of Shah and Laiwalla (in the presence of aluminium chloride dissolved in dry ether), formylation smoothly takes place with the formation of the Y-resorcylaldehyde derivative, methyl 2 : 4-dihydroxy-3-formyl benzoate (I),

the aldehyde group entering the usually inaccessible Y-position in the resorcinol nucleus (Shah and Laiwalla, *Current Science*, 1936, *5*, 197 ; *J.C.S.*, 1939, 1828). The aldehyde ester (I) has been found to be a suitable intermediate for synthesis of several coumarin derivatives, through the Knoevenagel condensation with ethyl malonate, ethyl-aceto-acetate and cyanacetic acid.

The most interesting application of this method is the synthesis of the hitherto unknown 5-hydroxy coumarin. 5-hydroxy-4-methyl coumarins are now readily obtained by the aluminium chloride method of Sethna, Shah and Shah (*loc. cit.*) but this method is obviously inapplicable for the synthesis of 5-hydroxy coumarin. This has been synthesized from methyl-2 : 4-dihydroxy-3-formyl-benzoate (I) through the stages methyl 4-methoxy-2-hydroxy-3-formyl benzoate (II) $\xrightarrow{\textit{malonic ester}}$ ethyl-5-methoxy-8-carbmethoxy-coumarin-3-carboxylate (III) $\longrightarrow$ 5-methoxy-coumarin-3 : 8-dicarboxylic acid (IV) $\longrightarrow$ 5-methoxy-coumarin (V) $\longrightarrow$ 5-hydroxy coumarin (VI) (H. A. Shah and R. C. Shah, *Current Science*, 1938, *7*, 107 ; *J.C.S.*, 1939, 1832).



(I) (II) (III)



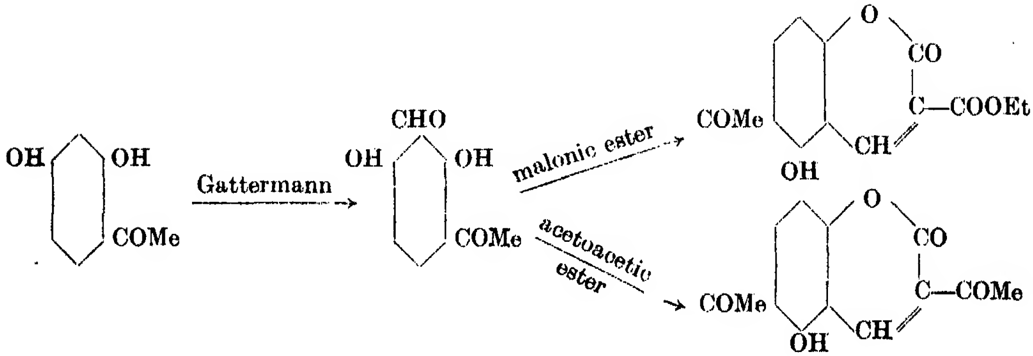
(IV) (V) (VI)

The modified Gattermann reaction above described is applicable also to polyhydroxy-phenolic ketones. In the case of resacetophenone, orsacetophenone and 2 : 4-dihydroxybenzophenone, in which the 3, i.e., the Y-position is free, formylation occurs in the 3-position (Shah and Shah, *Nature*, 1938, *142*, 163). 5-Hydroxy-coumarin derivatives are obtainable from these 3-formyl-hydroxyphenyl-ketones. Thus 2 : 4-dihydroxy-3-formyl-acetophenone by Knoevenagel condensation with malonic and aceto acetic esters affords ethyl 5-hydroxy-6-acetyl-coumarin-3-carboxylate and 5-hydroxy-3 : 6-diacetyl coumarin respectively. 7-Hydroxy-coumarin derivatives of the same type have been previously obtained by Weiss and Merckssammer (*Monatsch.*, 1928, *50*, 115) and Weiss and Kratz (*ibid*, 1929, *51*, 386) who prepared 7-hydroxy-3 :

6-diacetyl coumarin and 7-hydroxy-6-acetyl-coumarin-3-carboxylic acid by condensing resacetophenone with ethyl ethoxy-methylene-acetoacetate and ethyl ethoxy-methylene-malonate respectively in the presence of sodium ethoxide.

2-Acetyl resorcinol by the Gattermann reaction gives 2 : 4-dihydroxy-3-acetyl-benzaldehyde from which 7-hydroxy-3 : 8-diacetyl coumarin and 7-hydroxy-8-acetyl-coumarin-3-carboxylic acid have been prepared through the Knoevenagel reaction.

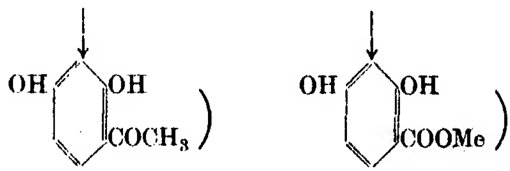
The synthesis of these hydroxy-formyl-phenyl-ketones, a class of compounds hitherto unknown, opens up various possibilities for the synthesis of heterocyclic compounds like furo-chromones, coumarino-chromones, etc., which are being explored.



The two apparently unconnected types of reactions referred to above, viz. the condensation of phenolic esters and ketones with B-ketonic esters in the presence of aluminium chloride to give 5-hydroxy-coumarin derivatives and the modified Gattermann reaction on phenolic esters and ketones to give 3-formyl derivatives, which have been serviceable for synthesis of some 5-hydroxy-coumarins, have a common theoretical basis. Both the phenomena, condensation in the first case and substitution in the second case at the 3- or Y-position, are due ultimately to the reactivity in the 3-, i.e. the Y-position in the resorcinol nucleus. This can be satisfactorily explained on the view that this is due to the stabilization of one of the kekule forms on account of chelation between the carbmethoxy or the acetyl group and the ortho-hydroxyl group.

The fixation of one of the kekule forms in the benzene nucleus was first suggested by Mills and Nixon (*J.C.S.*, 1930, 2510) in the case of compounds in which another ring is fused on to the benzene nucleas. Baker (*J.*, 1934, 1684) has explained the formation of 2 : 4-diacetyl-resorcinol from 4-0-acetyl resorcinol by assuming the stabilization of one of the kekule forms by chelation between the acetyl and the hydroxyl groups. It may be noted that Baker

suggests that aluminium chloride may prevent chelation, but the present experiments definitely show that aluminium chloride does not prevent chelation, and may even promote it. Further, as no case of 3-substitution in B-resorcylic acid or its ester was previously known, it has hitherto appeared that the chelation between the carbmethoxy group and the ortho-hydroxyl group in methyl B-resorcylate does not lead to a stabilization of one of the kekule forms (Baker, *loc. cit.*). The work on methyl B-resorcylate above referred to definitely points to the stabilization of one of the kekule forms under the experimental conditions.



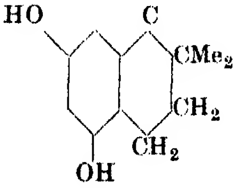
The author acknowledges the valuable collaboration in this work of his co-workers Mr. S. M. Sethna, M.Sc., Dr. N. M. Shah, M.Sc., Ph.D., Mr. H. A. Shah, M.Sc., and (the late) Mr. M. C. Laiwalla, M.Sc., who are responsible for all the experimental work.

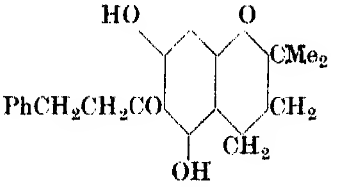
THE STRUCTURE OF ROTTLERIN. PART III.

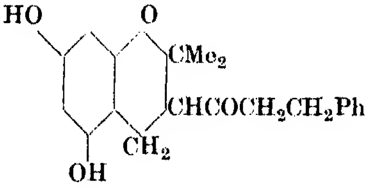
By KARTAR SINGH NARANG, JNANENDRA NATH RAY, *Ph.D., D.Sc., F.I.C.* *and* BHARPUR SINGH ROY, *The University, Lahore.*

(*Read at Symposium, September, 26-27, 1938.*)

In Part I[1] we described the methylation of rottlerin in acetone solution with dimethyl sulphate and potassium bicarbonate. The molecular weight of the methyl ether suggested[2,3] that rottlerin is $C_{27}H_{26}O_7$. Since then we discovered[2] that the N_2O_3 adduct of rottlerin methyl ether and the product of oxidation of the methyl ether with H_2O_2 are better explained on the basis of $C_{31}H_{30}O_8$ (5 OH groups). When the methyl ether of rottlerin (17 g.) is treated with sodium nitrite and acetic acid or butyric acid, an yield of 15·5 g. of the nitrosite is obtained. Therefore, it is clear that in the nitrosite formation the molecule neither breaks down nor does the acid participate in the reaction. In Part I we described a hydrolytic product $C_{20}H_{22}O_4$ of tetrahydro rottlerin. We suggested that this product may be identical with the product described by Robertson *et al*[4]. We have now methylated our product and find it to be identical with Robertson's product. Robertson *et al* have hydrolyzed this product and have isolated β-phenyl propionic acid and the chroman (I).


(I)


(II)


(III)

On the basis of this observation, they have advanced the view that this substance tetrahydro rottlerone has the structure (II). We are unable to accept this structure on the following grounds:—

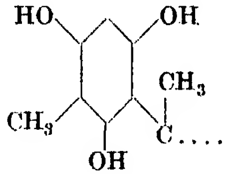
(*a*) The dimethyl ether of tetrahydro rottlerone does not give any indication of the formation of a pyrillium salt when saturated with hydrogen chloride in presence of salicylaldehyde in ether or acetic acid.

(*b*) Rottlerone, the corresponding unsaturated compound, does not isomerize to the related flavanone.

Therefore, we are of opinion that tetrahydro rottlerone is best represented by (III). We are engaged in finding support for this view.

(c) We are engaged in applying the Allen-Robinson reaction on tetrahydro rottlerone with benzoic anhydride. Formula II should give a flavone.

Now as regards the other half of the rottlerin molecule, recently Brockmann and Maier [5] have isolated by thermal decomposition of rottlerin in high vacuo at 180°–190° a yellowish sublimate which they have identified as methyl phloracetophenone. Mainly based on this observation and the rottlerone work of Robertson, they have advanced a tentative structure for rottlerin. In our opinion the formation of methyl phloracetophenone suggests the existence of the residue (IV) attached to the rottlerone half of the molecule (III).



(IV)

The formation of *iso* nitroso derivative in our opinion involves the opening up of the chroman ring and relactonization, a new phenolic hydroxy being generated in the process.

EXPERIMENTAL.

Tetrahydro rottlerone methyl ether (1 g.) (1 mol.) (Robertson *et al.*, *loc. cit.*), salicylaldehyde (1·25 mol.) in acetic acid (10 c.c.) or ether (50 c.c.) was saturated with hydrogen chloride in ice cold and left overnight. No indications were obtained of the formation of a pyryllium salt. Similarly rottlerone (1 g.) in alcohol (20 c.c.) was boiled with dilute acids but the substance decomposed and no definite product could be isolated.

Tetrahydro rottlerone.

A mixture of tetrahydro rottlerin (8·0 g.) in alcohol (400 c.c.), hydrochloric acid (d. 1·14, 80 c.c.) and water (40 c.c.) was heated for 26 hrs. The solution was filtered hot and the insoluble powder thus obtained was crystallized from ethyl acetate; yield 3·2 gm. (For analytical data vide Narang, Ray and Roy [1]). On methylation it gave a methyl ether, m.p. 102° (cf. Robertson *et al.*, *loc. cit*).

Action of alkali on the nitrosite ; formation of iso *nitrosite.*

The nitrosite described in earlier parts (2 g.) suspended in alcohol (15 c.c.) was treated with aqueous sodium hydroxide solution (10 c.c. of 33%). The mixture was warmed on the steam bath for 2 minutes and the alcohol removed in vacuo. The dark solution was diluted with water (80 c.c.) and extracted with ether. The aqueous portion on acidification with concentrated

hydrochloric acid furnished a sticky yellow solid which crystallized from alcohol in yellow plates, m.p. 153°; yield 1·3 g. This substance gave a violet ferric reaction. Found C, 63·57; H, 5·98; N, 4·11; $C_{36}H_{40}O_{11}H_2$ requires C, 63·9; H, 5·92; N, 4·14%.

The foregoing nitrosite (1·0 g.) dissolved in methanol (10 c.c.) was methylated with dimethyl sulphate (8 c.c.) and sodium hydroxide solution (25 c.c. of 30%). The temperature of the mixture was not allowed to rise. The sticky mass obtained by dilution with water (100 c.c.) was washed with water and finally crystallized from alcohol in bright yellow plates, m.p. 192°–193°; yield 0·6 g. Found C, 65·2; H, 6·02; N, 4·03; $C_{37}H_{42}O_{11}N_2$ requires C, 64·35; H, 6·09; N, 4·06%. $C_{38}H_{44}O_{11}N_2$ requires C, 64·77; H, 6·25; N, 3·98%.

REFERENCES.

[1] Narang, Ray and Roy, *J. Chem. Soc.*, 1862, (1937).
[2] Narang, Ray and Roy, *Current Sci.*, 7, 333, (1938).
[3] Narang, Ray and Roy, *Chem. Ind.*, (1938).
[4] Robertson *et al.*, *J. Chem. Soc.*, 748, (1937).
[5] Brockmann and Maier, *Annalen*, *535*, 154, (1938).

SYNTHETICAL EXPERIMENTS IN THE FLAVONE AND ISOFLAVONE GROUPS.

By K. VENKATARAMAN, *M.A., Ph.D., D.Sc., F.I.C., Department of Chemical Technology, The University, Bombay.*

(*Read at Symposium, September 26-27, 1938.*)

The wide occurrence of chromone derivatives in the roots, stems, bark, fruits, flowers and leaves of plants and their intimate relationship to the anthocyan group constituting the red, blue and purple pigments of fruits and flowers have stimulated wide interest in the chemical constitution of the naturally occurring representatives and methods for their synthesis. Their origin in plants is not known with certainty; they may originate at the point of vegetation, but are more frequently formed in the older tissue and their occurrence and definite localization often clearly indicate the relationship of plants in particular families, genera and species (Klein and Werner, *Z. physiol. Chem.*, 1925, **143**, 9). Their role in the plant economy is also somewhat uncertain; it has been suggested (Rouge, *Bull. Soc. Bot. Geneva*, 1921, **13**, 18) that they take part in the process of assimilation by absorbing oxygen and transporting it away from the cell. According to Ruszuyak and Szent-Gyorgyi (*Nature*, 1936, **138**, 27) this great group of vegetable dyes is allied to the vitamins, fulfilling an important function in plant and animal life. While flavones have been isolated from many plants of medicinal value, such as *Digitalis thapsi*, *Calycopteris floribunda*, *Cuscuta reflexa* and *Saponaria officinalis*, they do not appear to possess any pharmacological properties of practical interest (cf. Mahal, *Proc. Ind. Acad. Sc.*, 1937, **5**, 186).

The older methods, due largely to Kostanecki, for the synthesis of flavones and flavonols had certain limitations (Venkataraman, *J. Ind. Chem. Soc., Sir P. C. Ray Commem. Vol.*, 1933, 28), which led Robinson to seek a reaction of wider utility (Allan and Robinson, *J. Chem. Soc.*, 1924, **125**, 2193 *et sequa*). The possibilities of an early observation of Tahara (*Ber.*, 1892, **25**, 1302) regarding the prolonged action of acetic anhydride on resacetophenone soon became apparent and a general synthesis of flavones and flavonols was developed by Robinson, in which *o*-hydroxyaryl alkyl ketones were heated with the appropriate acid anhydride and the sodium salt of the acid. Thus the interaction of benzoic anhydride and phloracetophenone and alkaline hydrolysis of the product yielded chrysin, the colouring matter of poplar buds (Robinson and Venkataraman, *J. Chem. Soc.*, 1926, **129**, 2344). By the application of the Robinson method in its simplest form or involving in addition methylation or complete demethylation with hydriodic acid, the following naturally occurring flavones and flavonols have been synthesised: flavone (the parent

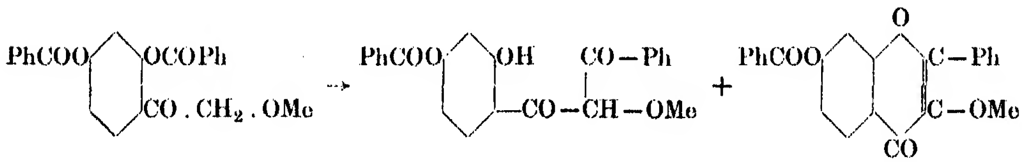
 [Published June 5th, 1939.

member of the series), chrysin, acacetin, pratol, luteolin, galangin, kæmpferol, fisetin, quercetin, morin, robinetin, herbacetin, tangeritin, myricetin, gossypetin and quercetagetin.

The Robinson reaction proceeded smoothly in the case of ω-substituted ketones derived from *m*-dihydric phenols, e.g. ω-methoxyresacetophenone and ω-methoxyphloracetophenone, but although several naturally occurring and other flavones (unsubstituted in the 3-position) have been successfully prepared by the Robinson method, a careful study of the process revealed complexities. Under the right conditions the chromone condensation is applicable not only to resacetophenone and its derivatives, but also to *o*-hydroxyacetophenone, 2: 5-dihydroxyacetophenone, 1-acetyl-2-naphthol and 2-acetyl-1-naphthol. It was found, however, in the case of 2-acetyl-1-naphthol that the major product of the reaction was a 3-aroyl chromone and it has since been shown that such 3-acylation is a source of confusion and experimental difficulty in carrying out the Robinson synthesis (*J. Chem. Soc.*, 1931, 1165; 1933, 1074; Anderson, *Canadian J. Research*, 1932, **7**, 285). The mechanism of the reaction and alternative procedures precluding 3-acylation were therefore investigated. Failure to effect ring closure to the γ-pyrone in *o*-acyl derivatives of *o*-hydroxyketones (e.g. in 2-acetyl-1-naphthyl benzoate and in 2-phenylacetyl-1-naphthyl benzoate in which the ω-phenyl might be expected to facilitate chromone formation) indicated that the commonly assumed mechanism of the reaction (cf. Wittig, Baugert and Richter, *Ann.*, 1925, **446**, 155) needed experimental verification. At least one example, however, of direct dehydration of an *o*-benzoyloxyphenyl alkyl ketone to the chromone is available in the conversion of ω-2: 4: 6-tetrabenzoyloxyacetophenone to galangin tribenzoate by means of boiling alcoholic potassium acetate (Chavan and Robinson, *J. Chem. Soc.*, 1933, 368).

The action of an acid anhydride and the sodium salt of an acid on a phenolic ketone may lead to the acyl derivative of the ketone, a chromone, a 3-acylated chromone, or a coumarin. The reaction could be limited to the formation of the *o*-acyl derivative of the ketone by brief heating, preferably in the absence of the sodium salt and the presence of pyridine. The course of the reaction with regard to the other three alternatives is dependent both on the nature of the ketone and of the acid anhydride. An ω-substituent is an aid to chromone formation, which also takes place more readily in the naphthalene than in the benzene series. With an *o*-hydroxyaryl methyl ketone, the deciding factor is essentially the acid anhydride. The anhydride of an acid such as phenylacetic acid containing a reactive methylene group yields the coumarin always. Coumarin formation being precluded in the case of aromatic acid anhydrides, flavones and 3-aroyl flavones are formed. The interaction of aliphatic acid anhydrides with *o*-hydroxyaryl methyl ketones is of a complicated character and both coumarins and chromones (including 3-acyl chromones) are producible.

So far as the action of aromatic acid anhydrides on *o*-hydroxyaryl methyl ketones is concerned, the mechanism of chromone synthesis has been demonstrated by Baker (*J. Chem. Soc.*, 1933, 1381) as involving the intermediate formation of a dibenzoylmethane. While Baker achieved the transformation of *o*-acyloxyacetophenones to the dibenzoylmethanes by means of potassium carbonate in toluene at 100°, the tautomerisation of 2-acetyl-1-naphthyl benzoate in ether solution to ω-benzoyl-2-acetyl-1-naphthol by means of sodamide at room temperature was observed simultaneously in Lahore (Mahal and Venkataraman, *Current Science*, 1933, 4, 214; *J. Chem. Soc.*, 1934, 1767). As the diketone could be cyclicised to the flavone also at room temperature, the process was of interest from the point of view of the phytochemical synthesis of flavones and flavone glykosides. Other observations relating to the reaction mechanism were the isolation of a 2-hydroxy-naphthaflavanone, a type postulated by Baker as an intermediate stage in the conversion of his diketones into flavones, from the products of the interaction of 2-benzylacetyl-1-naphthol with ethyl formate and sodium (Cheema and Venkataraman, *J. Chem. Soc.*, 1932, 918); and the thermal transformation (by distillation in high vacuum) of ω-methoxyresacetophenone dibenzoate to a mixture of the diketone (I) and the flavone (II) (Mahal, Ph.D. thesis, Panjab University, 1936).



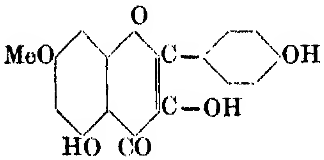
(I) (II)

Modifying the original Robinson method by using benzoyloxy or benzyloxy-derivatives in the ketone or acid anhydride parts of the reaction mixture and taking advantage of the more facile removal of the benzoyl and benzyl groups in comparison with methyl ethers, partially methylated polyhydroxyflavones —kæmpferide, syringetin, diosmetin, tricin—have been prepared (Heap and Robinson, *J. Chem. Soc.*, 1926, 2336; 1929, 68; Lovecy, Robinson and Sugasawa, *J. Chem. Soc.* 1930, 817; Gulati and Venkataraman, *J. Chem. Soc.*, 1933, 942).

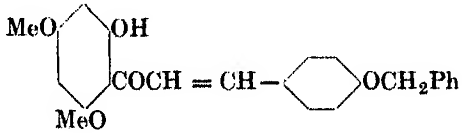
Selenium dioxide is a specific oxidising agent for the conversion of methylene to carbonyl (Müller, *Ber.*, 1933, **66**, 1668; Evans, Ridgeon and Simonsen, *J. Chem. Soc.*, 1934, 137), but when 2: 3-dihydro-α-naphthaflavone in xylene was heated with selenium dioxide, the product was the naphthaflavone and not the naphthaflavonol. *o*-Hydroxychalkones may thus be directly oxidised to flavones (Mahal, Rai and Venkataraman, *J. Chem. Soc.*, 1935, 866). 7-Methoxy-4′-hydroxyflavone was synthesised in this manner from 2-hydroxy-4-methoxyphenyl 4′-benzyloxystyryl ketone, followed by debenzylation, and found to be different from a hydroxymethoxyflavone isolated by Adrian and

Trillat (*Comp. rend.*, 1899, **129**, 889) from a species of *Digitalis*. In view of the smooth dehydrogenation of chalkones and flavanones to flavones, the utility of selenium dioxide for the dehydrogenation of hydroaromatic to aromatic compounds has been examined; by heating tetrahydronaphthalene with selenium oxide at 160° for 24 hours a 30% yield of naphthalene was obtainable (Mahal, *loc cit.*).

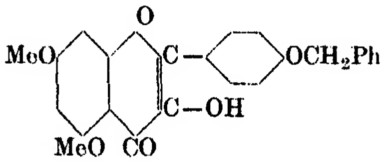
Algar and Flynn (*Proc. Royal Irish Acad.*, 1934, Series B, 42, separate issue) have accomplished the synthesis of flavonols from chalkones by oxidation with alkaline hydrogen peroxide. Attempting to utilise this reaction for the synthesis of kæmpferol 7-methyl ether (III), a substance of interest with regard to the structure of rhamnocitrin (Oesch and Perkin, *J. Chem. Soc.*, 1914, **105**, 2332), 2-hydroxy-4: 6-dimethoxyphenyl 4-benzyloxystyryl ketone (IV) was treated with alkaline hydrogen peroxide under a variety of conditions, but the flavonol (V), which could then be debenzylated and partially demethylated to (III), was not obtained, the pale yellow needles, m.p. 198°, exhibiting the properties of a flavanone.



(III)

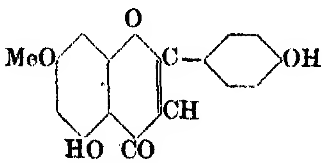


(IV)

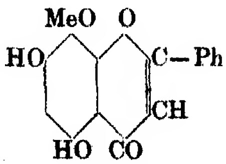


(V)

The 5-hydroxyl in a flavone is analogous to the *o*-hydroxyl of a ketone, chelation being possible in both cases; methylation can only be effected under special conditions and the methyl ether is more readily demethylated than methoxyls in other positions. Such partial demethylation of polymethoxyflavones to the 5-hydroxy derivatives can be carried out with aluminium chloride, a process which has proved useful for the synthesis of partially methylated polyhydroxyflavones. Genkwanin (VI) and wogonin (VII) have thus



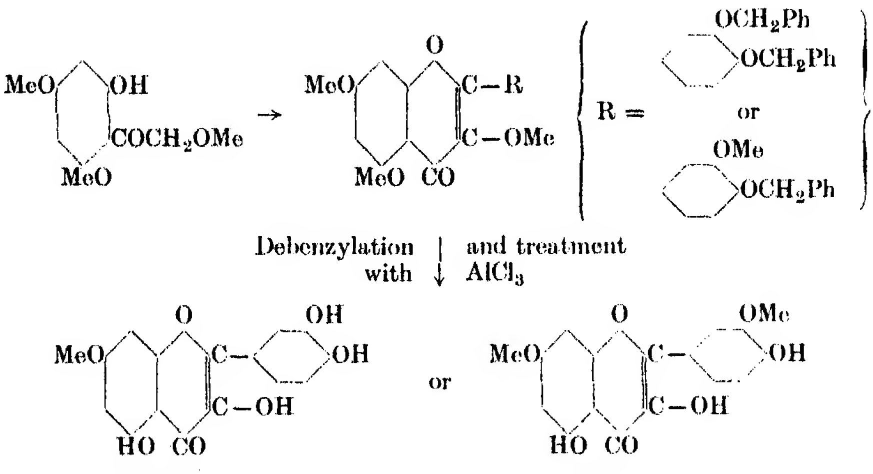
(VI)



(VII)

been synthesised (Mahal and Venkataraman, *J. Chem. Soc.*, 1936, 569; Mehta, Shah and Wheeler, *in print*), and the reaction has thrown light on the constitution of calycopterin, although further work has shown that the suggested structure (Mahal and Venkataraman, *Current Science*, 1935, 311) must be confirmed by additional evidence, which is now being sought. While the synthesis of 5 : 7 : 2′ : 4′-tetrahydroxyflavone (Robinson and Venkataraman, *J. Chem. Soc.*, 1929, 66; cf. Cullinane, Algar and Ryan, *Proc. Royal Soc. Dublin*, 1928, **19**, 77) leaves little doubt regarding its non-identity with lotoflavin (Dunstan and Henry, *Phil. Trans.*, 1901, **194**, 515), the properties of lotoflavin trimethyl ether, which crystallised in dimorphic forms with different melting points, were more characteristic than those of lotoflavin. It would, therefore, be desirable to synthesise 5-hydroxy-7 : 2′ : 4′-trimethoxyflavone, for comparison with lotoflavin trimethyl ether, by the controlled demethylation with aluminium chloride of the tetramethyl ether, which may be conveniently prepared by the selenium dioxide oxidation of 2-hydroxy-4 : 6-dimethoxyphenyl 2 : 4-dimethoxystyryl ketone.

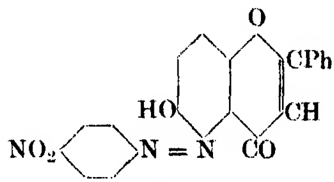
The 3-methoxyl group in a flavone is also sensitive to hydrolysis by aluminium chloride, and this may be utilised for the preparation of methoxyflavonols, the following being feasible schemes for the synthesis of rhamnetin (VIII) and rhamnazin (IX):



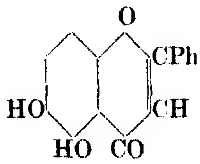
(VIII) (IX)

The reactivity of plant dyestuffs derived from resorcinol and phloroglucinol towards diazo salts has been studied by Perkin (*J. Chem. Soc.*, 1895, **67**, 933), who used it for characterising such phenolic colouring matters. While Perkin found that chrysin, apigenin, euxanthone and catechin all gave *dis*-azo dyes, the coupling of 6-hydroxyflavone with diazotised *p*-nitraniline yields a *mono*-azo dye, which in consideration of the fixation of the double

bonds in the fused benzene ring of the chromone nucleus may be assumed to have the structure (X) (Mahal and Venkataraman, *Current Science*, 1938, **6**, 450). A route to the synthesis of



(X)



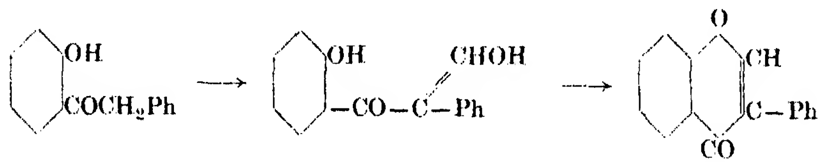
(XI)

primetin (XI) then becomes possible. The coupling of chrysin or its 7-benzyl ether with a diazo salt of low coupling energy might lead to the 8-*mono*-azo dye, a reaction of potential value for the transformation of 5: 7-dihydroxyflavones into the 5: 7: 8-trihydroxy derivatives (e.g. chrysin→norwogonin; 7-benzyl chrysin→wogonin; quercetin→gossypetin). Likewise the coupling of 5- or 8-hydroxyflavones with a suitable diazo salt may be utilised for the synthesis of the 5: 8-dihydroxy derivatives. Such an orientation of hydroxyls has been suggested for the colouring matter of *Gingko biloba* (Furukawa, *Sci. Papers Inst. Phys. Chem. Res., Tokyo*, 1933, **21**, 278).

Nierenstein's conversion of quercetin to gossypetin has been unconfirmed (Baker, Nodzu and Robinson, *J. Chem. Soc.*, 1930, 922) and norwogonin (Hattori, *Acta Phytochim.*, 1932, **6**, 183) bore no resemblance to Nierenstein's 8-hydroxychrysin (*Ber.*, 1912, **45**, 490). Attempts in this laboratory to oxidise chrysin by means of chromic anhydride and with other oxidising agents (nitric acid, potassium persulphate, selenium dioxide) did not lead to any homogeneous material other than the starting substance. Oxidation of 5-hydroxy-6-benzyl-7-benzyloxyflavone also gave negative results. The ready oxidisability of pyrogallol trimethyl ether to 2: 6-dimethoxyquinone suggested that oxidation of 7: 8-dihydroxyflavone might yield norwogonin, but numerous attempts to oxidise this flavone, as well as its dimethyl and dibenzyl ethers, have been fruitless; further experiments on these lines are, however, indicated.

While flavones have been extensively studied since 1873, our knowledge of the *iso*flavone group is much more recent. The first natural product to be recognised as an *iso*flavone was prunetin (Finnemore, *Pharm. J.*, 1910, **31**, 1761); Baker and Robinson (*J. Chem. Soc.*, 1926, **127**, 2713) demonstrated the identity of demethyl prunetin or 5: 7: 4′-trihydroxy*iso*flavone with genistein, the colouring matter of dyer's broom. Since then several other *iso*flavones have been isolated from plants. The first synthesis of an *iso*flavone was carried out by Baker and Robinson (*J. Chem. Soc.*, 1925, **127**, 1981) by the oxidation of 7-methoxy-2-styryl-3-phenylchromone to the 2-carboxylic acid, which was decarboxylated to 7-methoxy*iso*flavone. Genistein and daidzein

were later synthesised similarly, but in the case of irigenol (5 : 6 : 7 : 3′ : 4′ : 5′-hexahydroxy*iso*flavone) the oxidation of the 2-styryl derivative of the hexamethyl ether proved impracticable (Baker and Robinson, *J. Chem. Soc.*, 1929, **135**, 152). Baker, Pollard and Robinson (*J. Chem. Soc.*, 1929, **135**, 1468) developed a second synthesis of *iso*flavones involving a Hoesch reaction on the cyanhydrin of an ω-phenoxyacetophenone, which was applied by Späth and Lederer (*Ber.*, 1930, **63**, 743) to ψ-baptigenin, but was inadequate for other syntheses in the field (Baker, Morgan and Robinson, *J. Chem. Soc.*, 1933, **143**, 374). The third synthesis, due to Späth and Lederer, consisted in heating derivatives of 2-hydroxyphenyl benzyl ketone with ethyl formate and sodium in a sealed tube, followed by treatment of the reaction mixture with boiling alcohol and fuming hydrochloric acid in order to effect cyclisation of the oxymethylene compound (XII), assumed to be an intermediate product, to the *iso*flavone (XIII).

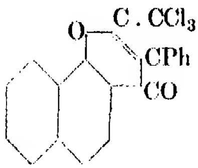


(XII) (XIII)

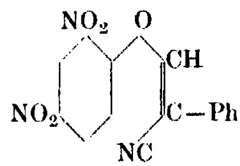
By sublimation in high vacuum, poor yields of the *iso*flavones (ψ-baptigenin, daidzein and formononetin) were obtained (Späth and Lederer, *loc. cit.*, Wessely, Kornfeld and Lechner, *Ber.*, 1933, **66**, 685). The action of sodium on an ice-cooled solution of *o*-hydroxyphenyl benzyl ketones in ethyl formate proceeds, however, in one stage to the *iso*flavone (Joshi and Venkataraman, *J. Chem. Soc.*, 1934, 513); a series of *iso*flavones—*iso*flavone, the parent member, 7-hydroxy*iso*flavone, α- and β-naphtha*iso*flavone, formononetin, daidzein and ψ-baptigenin—have thus been synthesised with simplicity and in excellent yields; and the method should also be applicable to irigenol along obvious lines.

Some negative experiments in the *iso*flavone group may be recorded. The action of trichloracetic anhydride and potassium trichloracetate on 2-phenylacetyl-1-naphthol gave a substance, which had the qualitative properties of 2-trichlormethyl-3-phenyl-1 : 4-α-naphthapyrone (XIV), but it could not be crystallised and hydrolysis to the 2-carboxylic acid and decarboxylation to the naphtha*iso*flavone were not accomplished.

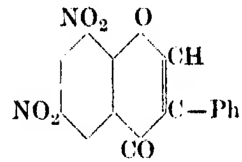
2 : 4-Dinitrobrombenzene condensed with α-formylphenylacetonitrile in pyridine solution to give 2 : 4-dinitrophenoxymethylene benzyl cyanide (XV). Saturation of an ethereal solution of (XV) with hydrogen chloride gave a substance, m.p. 188°, which was not the dinitro*iso*flavone (XVI); nor was it the pyrone-imide (XVII),



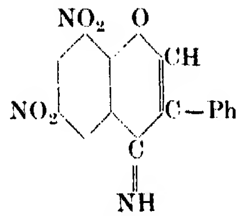
(XIV)



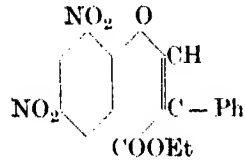
(XV)



(XVI)

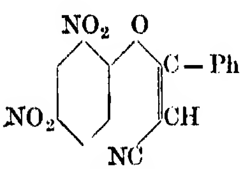


(XVII)

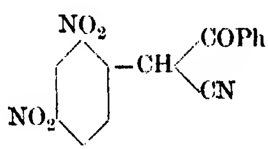


(XVIII)

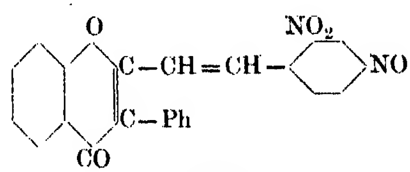
being unaffected by boiling concentrated hydrochloric acid and syrupy phosphoric acid. Similarly to (XV), the dinitrophenoxymethylene phenylacetic ester (XVIII) was prepared; attempts to effect ring closure to (XVI) were unsuccessful.



(XIX)



(XX)



(XXI)

Condensing 2 : 4-dinitrobrombenzene with benzoylacetonitrile in presence of sodium ethylate, two substances, the *O*-phenyl and the *C*-phenyl derivatives (XIX) and (XX), were isolated. Treatment of (XIX) with hydrogen chloride in ether yielded the unconverted substance or uncrystallisable material.

In the Baker-Robinson method for the synthesis of *iso*flavones by the oxidation of their 2-styryl derivatives, the possibility of the use of the dinitrostyryl compound (XXI) leading to more facile oxidation could not be examined, since 2 : 4-dinitrobenzaldehyde did not condense with 2-methyl-3-phenyl-1 : 4-α-naphthapyrone, which reacts readily with benzaldehyde, anisaldehyde and veratraldehyde (Cheema, Gulati and Venkataraman, *J. Chem. Soc.*, 1932, 926).

β-Naphthol condenses with ethyl acetoacetate to give a chromone (Dey and Lakshminarayanan, *J. Indian Chem. Soc.*, 1932, 9, 153), but the α-pyrone was obtained in the case of α-formylphenylacetic ester.

THE COLOURING MATTER OF THE YELLOW FLOWERS OF *THEVETIA NERIFOLIA* (APOCYANACEAE).

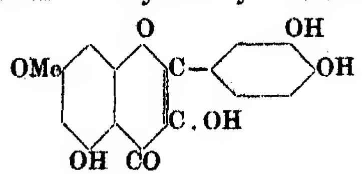
By R. D. DESAI, *St. Xavier's College, Bombay, and* ZAFARUDDIN AHMAD, *Muslim University, Aligarh.*

(*Read at Symposium, September 26-27, 1938.*)

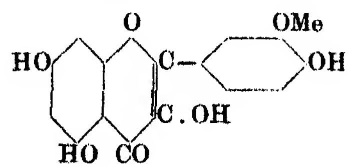
The yellow flowers of *Thevetia Nerifolia*, commonly known as the *yellow oleander* in English, *Pili Kaner* in Hindi and *Pili Karan* in Gujarati, have not been examined for their colouring matter. The systematic examination which we have undertaken has not reached the stage of completion, but as the resumption of the work in the near future has been delayed, we have thought it advisable to publish the results obtained by us so far.

The alcoholic extract of the dried flowers gave two colouring matters which were present as glucosides, but as it was not possible to isolate the glucosides themselves, we obtained the colouring matters by hydrolysing them with 10 per cent sulphuric acid. The first colouring matter, obtained in very small amounts, did not melt up to 360°, and was an amorphous brown powder, soluble in alkali and alkaline carbonates with a red colour. Its solution in concentrated sulphuric acid gave dark greenish fluorescence, and did not give positive colour tests for the flavone group. As it was not obtained in a sufficient amount, its further investigation was not proceeded with.

The second colouring matter crystallised from alcohol in small, yellow needles melting at 260° and its alcoholic solution gave immediately a pink colour with magnesium and hydrochloric acid. Its yellow, alkaline solution was decolourised by air, hence it was a flavanol derivative with a free hydroxyl group in 3 position. It dissolved in concentrated sulphuric acid giving a pale-yellow solution with an intense green fluorescence. Its alcoholic solution gave a greenish-black coloration with ferric chloride. It gave a tetra-acetyl derivative, contained one methoxyl group and, on demethylation, gave quercetin. Therefore, it was a mono-methyl ether of quercetin, but did not correspond with either rhamnetin (I) or isorhamnetin (II) in properties. Therefore, it is assumed that it may be the 4'-methyl ether (III) of quercetin, and we intend to synthesise it by condensing *w*-benzyloxyphloraceto phenone with isovanillic anhydride by the Allan-Robinson method.

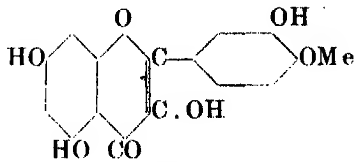


(I)



(II)

 [Published June 5th, 1939.



(III)

EXPERIMENTAL.

The dried flowers (500 g.) were thrice extracted with rectified spirit by refluxing on water-bath for 8 to 10 hours. After the removal of alcohol under reduced pressure, the dried residue was refluxed with petrol (b.p. 40–60°) which removed a considerable amount of a yellow, neutral material which has not yet been examined. As the petrol-insoluble residue did not show any tendency to crystallise from the usual organic solvents, its aqueous solution was alternately treated with lead acetate and basic lead acetate. Both the precipitates were separately suspended in water and decomposed with hydrogen sulphide. As the lead-acetate precipitate contained mostly the tannins and the phlobaphenes, it was not further examined. After the removal of lead sulphide, the aqueous filtrate from the basic lead-acetate precipitate was concentrated under vacuum, and boiled for 15 minutes after the addition of 10 per cent sulphuric acid (25 c.c.). The copious, yellowish brown precipitate was collected, dried and purified. (Yield 2 gms.) The aqueous filtrate reduced Fehling's solution at once showing the presence of a reducing sugar.

The crude colouring matter (m.p. 180–210°) was treated with rectified spirit which dissolved most of the substance leaving a small residue which did not melt up to 360°. Its properties have already been described in the introductory portion. The alcohol-soluble portion after several recrystallisations from the same solvent crystallised in small, yellow needles melting at 260°. (Found C, 64·6; H, 4·1; OMe, 9·4. $C_{15}H_9O_6OCH_3$ requires C, 64·9; H, 4·0; OCH_3, 9·8 per cent.)

The Tetra-acetyl derivative was obtained by heating the substance (0·2 g.) with acetic anhydride (5 c.c.) and anhydrous sodium acetate (1 g.) for three hours on the sand-bath and crystallised from alcohol in pale-yellow needles melting at 165°. (Found C, 59·2; H, 4·3. $C_{24}H_{20}O_{11}$ requires C, 59·5; H, 4·1 per cent.)

Demethylation to Quercetin. A mixture of the substance (0·5 g.), glacial acetic acid (10 c.c.) and hydriodic acid (5 c.c. d = 1·84) was heated for three hours on sand-bath, and poured into a large quantity of water. The flocculent precipitate that came out slowly was gathered and crystallised from alcohol. It was identified as quercetin by comparing it with an authentic specimen, kindly supplied by Dr. S. B. Dutt of Allahabad to whom our thanks are due.

THE CONSTITUTION OF OROXYLIN-A. PART II. ATTEMPTED SYNTHESIS OF OROXYLIN-A AND THE SYNTHESIS OF WOGONIN.

By R. C. SHAH, *Ismail College*, C. R. MEHTA, *Seth G. S. Medical College and* T. S. WHEELER, *Ph.D., D.Sc., F.I.C., Royal Institute of Science, Bombay.*

(*Read at Symposium, September 26-27, 1938.*)

Attempted synthesis of Oroxylin-A. In an attempt to synthesise (I), 2:5-dimethoxyresorcinol was converted into 2:4-dihydroxy-3:6-dimethoxy-acetophenone (II; Wessely and Moser, *Monatsch.*, 1930, *56*, 97), which was fused with benzoic anhydride and sodium benzoate; since the *product* (m.p. 287-288°) was a hydroxydimethoxy- and not a dihydroxymethoxy flavone, it must be 7-hydroxy-5:8-dimethoxyflavone (III) and not (I; m.p. 231-232°). This is confirmed by the fact that on methylation (III) gave a trimethoxyflavone (m.p. 167-168°), which is not (mixed m.p. comparison with oroxylin-A dimethyl ether) 5:6:7-trimethoxyflavone (m.p. 163-164°; Hattori, *Acta Phytochim.*, 1930, *5*, 99) but corresponds (mixed m.p.) to 5:7:8-trimethoxyflavone (IV; m.p. 167-168°; Hattori, *loc. cit.*) obtained for purpose of comparison by methylation of authentic wogonin (VII).

Anisoylation of (II) has been studied by Wessely and Moser (*loc. cit.*), who report the unexpected formation of 5:7-dihydroxy-6:4′-dimethoxyflavone and this result has been confirmed by Wessely and Kallab (*Monatsch.*, 1932, *60*, 26). Furukawa and Tamaki [*Bull. Inst. Phys. Chem. Research (Tokyo)*, 1931, *10*, 732; cf., Hattori, *Acta Phytochim.*, *loc. cit.*, and 1931, *5*, 219], however, claim that anisoylation proceeds normally to give 7-hydroxy-5:8:4′-trimethoxyflavone. Baker *et al.* (*loc. cit.*) and Goldsworthy and Robinson (*J.C.S.*, 1938, 56), who have studied respectively the veratroylation and anisoylation of the ω-methoxy-derivative of (II), also obtained 5:7:8-derivatives.

Demethylation of O-alkylated 5:7:8-trihydroxyflavones. Demethylation of (III) by hydriodic acid proceeded abnormally, the product (m.p. 265-266°) isolated pure in moderate yield being 5:6:7-trihydroxyflavone (V; mixed m.p. comparison and characteristic baicalein alkali colour reaction) instead of the expected 5:7:8-derivative (VI). Rearrangement of a 5:7:8- to a 5:6:7-trihydroxyflavone during hydriodic acid demethylation has been observed previously by Wessely and Moser (*loc. cit.* cf. Furukawa quoted by Hattori, *Acta Phytochim.*, 1931, *5*, 225) who obtained 5:6:7:4′-tetrahydroxyflavone (scutellarein) from 7-hydroxy-5:8:4′-trimethoxyflavone. Normal demethylation to gossypetin has, however, been obtained by Baker *et al.* (*loc. cit.*) with 7-hydroxy-3:5:8:3′:4′-pentamethoxyflavone; by Hattori (*Acta Phytochim.*, 1930, *5*, 99) with wogonin (VII; 5:7-dihydroxy-8-methoxyflavone) and

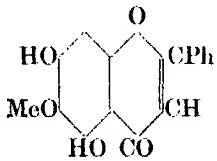
5: 7: 8-trimethoxyflavone, and (*loc. cit.*, 1931, *5*, 219) with 7: 8-dimethoxy-5-ethoxyflavone; by Furukawa and Tamaki (*loc. cit.*) with 7-hydroxy-5: 8: 4′-trimethoxyflavone and by Goldsworthy and Robinson (*loc. cit.*) with 7-hydroxy-3: 5: 8: 4′-tetramethoxyflavone. On the other hand Wessely and Kallab (*loc. cit.*) in a re-examination of the previous work of Wessely and Moser (*loc. cit.*) claim that contrary to the results of Hattori (*Acta Phytochim.*, 1931, *5*, 219), rearrangement to scutellarein occurs on demethylation of 5: 7: 8: 4′-tetramethoxyflavone with hydriodic acid. Further evidence on this point is afforded by the following observations:—Demethylation of (III) by means of anhydrous aluminium chloride (1–3 mols.) gave a trihydroxyflavone (m.p. 250-251°) which gave an alkali colour reaction distinct from that of baicalein; it dissolved in dilute alkali with a scarlet colour, which rapidly changed through green to yellow with a tinge of green, without separation of green flocks. It cannot, therefore, be baicalein and this view was confirmed by a mixed m.p. comparison which was depressed; it can only be 5: 7: 8-trihydroxyflavone (VI). Hattori's product (*Acta Phytochim.*, 1930, *5*, 99 and *loc. cit.*; cf. Nierenstein, *idem*, 1932, *6*, 173; Hattori, *idem*, 176), on the other hand, which was obtained by the action of hydriodic acid on wogonin, 5: 7: 8-trimethoxyflavone, 7: 8-dimethoxy-5-ethoxyflavone and 2: 3: 4: 6-tetramethoxy-dibenzoylmethane, had m.p. 226-227°, and was regarded by him as 5: 7: 8-trihydroxyflavone, although only acetyl derivatives were analysed.

A re-examination of the hydriodic acid demethylation of natural wogonin (VII) gave a product with m.p. 247-248°, depressed by admixture with (VI; m.p. 250-251°) but not depressed by addition of baicalein (m.p. 264°). Further, this new product gave the characteristic alkali colour reaction for baicalein. Hattori reports for his product (m.p. 226-227°) an alkali colour reaction similar to that given by baicalein (*Acta Phytochim.*, 1935, *5*, 109). It thus appears that Hattori's product was contaminated with baicalein and that pure 5: 7: 8-trihydroxyflavone of m.p. 250-251° has been obtained for the first time in the course of this work.

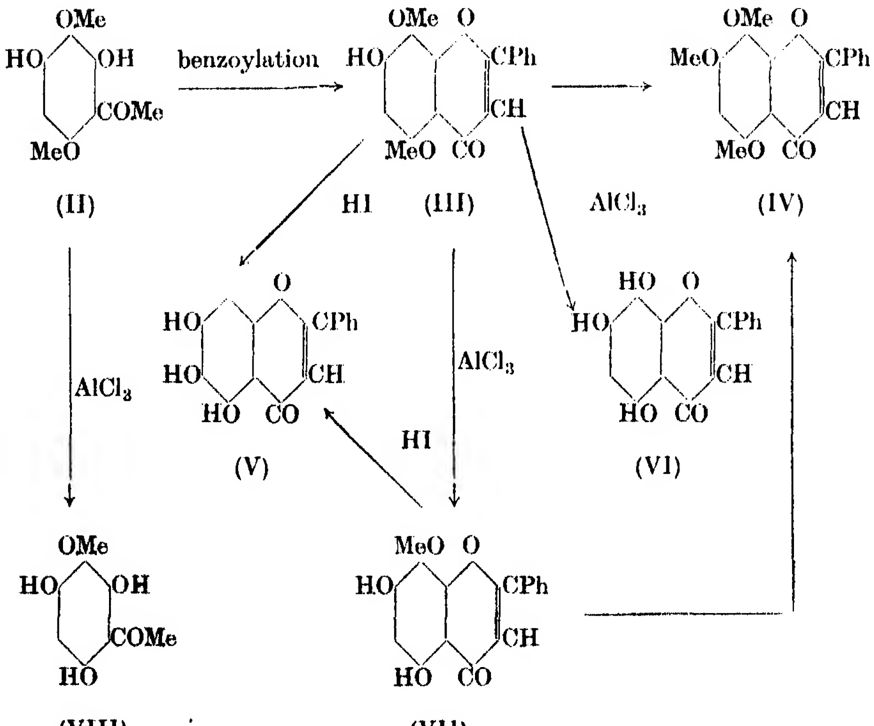
The disagreement among various workers in regard to the action of hydriodic acid on 0-alkylated 5: 7 : 8-trihydroxyflavones is probably due to the difficulty of isolation of pure products when dealing with small quantities of material. It is suggested that demethylation is accompanied by opening of the pyrone ring followed by ring-closure with formation of a 5: 6: 7- or a 5: 7: 8-trihydroxyflavones or a mixture of both. Of interest in this connection is the fact that 2: 3: 4: 6-tetra- and 2: 3: 4: 6: 4′-pentamethoxydibenzoylmethanes give mixtures of 5: 6: 7- and 5: 7: 8-derivatives on treatment with hydriodic acid (Bargellini, *Gazzetta*, 1919, *49*, ii, 47; Hattori, *Acta Phytochim.*, 1931, *5*, 219).

If these contentions are correct, then it is unsafe to assign a 5: 6: 7-structure to an alkoxyflavone because it gives a 5: 6: 7-trihydroxyflavone on treatment with hydriodic acid, unless remethylation is carried out for the purpose of further comparison; aluminium chloride would appear to be a safer demethylating agent. In Part I (*J.C.S.*, 1936, 591) emphasis was laid on the

fact that demethylation of oroxylin-A with hydriodic acid gave baicalein; we no longer regard this evidence of structure as cogent, and prefer to base the constitution assigned to oroxylin-A on its colour reactions, and the correspondence of its O-alkylated derivatives with those of baicalein.



(I)



Synthesis of wogonin. Wogonin which has not previously been synthesised was isolated by Takahashi (*Chem. Zent.*, 1889, II, 620) from the roots of *Scutellaria baicalensis* Georgi. Its constitution was first investigated by Shibata, Iwata and Nakamura (*Acta Phytochim.*, 1923, *1*, 105) and later by Hattori (*Acta Phytochim.*, 1930, *5*, 99) who assigned to it the structure 5:7-dihydroxy-8-methoxyflavone (1 H_2O; VII). Partial demethylation of (III) was effected with aluminium chloride under mild conditions (Gulati and

Venkataraman, *J.C.S.*, 1936, 267) with production of a dihydroxymethoxy-flavone, having m.p. 200-201, not depressed by admixture with a sample of authentic natural wogonin to which it corresponded in analysis and properties. Methylation of the synthetic product with diazomethane gave 5-hydroxy-7:8-dimethoxyflavone, and with dimethyl sulphate and alkali, 5:7:8-trimethoxy-flavone (IV; identical with the methylation product of III) with properties in agreement with those described for these products by Hattori (*loc. cit.*).

(II) was partially demethylated with aluminium chloride to a mono-methoxy-ketone which is presumably the iretol derivative 2 : 4 : 6-trihydroxy 3-methoxyacetophenone (VIII), the 5-methoxy-group being, it is assumed, preferentially attacked. This ketone was benzoylated by the fusion method in the hope of obtaining (I) but no definite product could be isolated.

SYNTHESIS OF SOME NATURALLY-OCCURRING FLAVONES FROM CHALKONES.

By T. S. WHEELER, *Ph.D., D.Sc., F.I.C., F.N.I., Royal Institute of Science, Bombay, and* Collaborators.

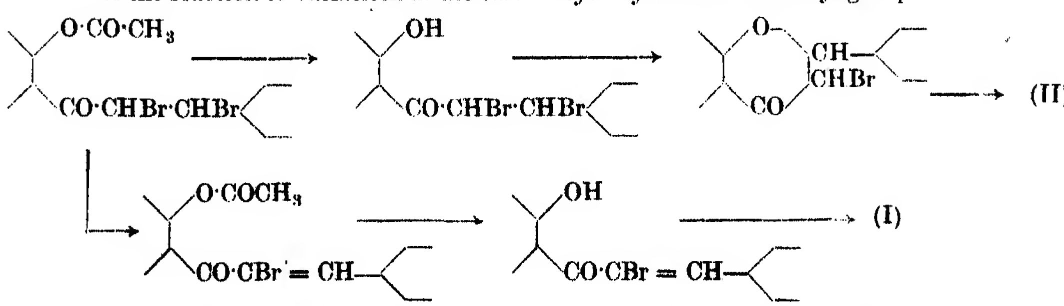
(*Read at Symposium, September, 26-27, 1938.*)

INTRODUCTION.

The flavones, as is well known, form a group of naturally-occurring chemical compounds widely distributed in the plant world. For some time past this laboratory has been engaged in a study of the production of flavones from chalkones. The first synthesis of flavones in this way was accomplished by heating the dibromides of certain *o*-acetoxychalkones with alcoholic alkali (Emilewicz and Kostanecki, *Ber.*, 1898, **31**, 696). This synthesis was, however, found to be unreliable; in certain cases benzylidenecoumaranones (I) were obtained instead of the expected flavones (II).

(I) (II)

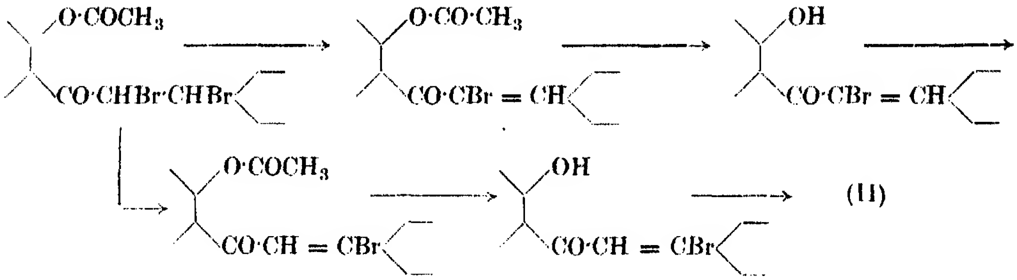
Kostanecki and Tambor (*Ber.*, 1899, **32**, 2268) attributed the dual course of the reaction to variations in the ease of hydrolysis of the acetoxyl group:—



and owing to the uncertainty of the course of the reaction, Kostanecki devoted himself to the development of other methods for the synthesis of flavones.

Auwers and Anschütz (*Ber.*, 1921, **54**, 1543) showed that the above view needed modification, since non-acetylated *o*-hydroxychalkone dibromides behaved similarly; they found that low temperatures favoured the production of a flavone from a chalkone dibromide but were unable to offer any explanation of the fact.

Ryan and Ryan (*Proc. Roy. Irish. Acad.*, 1930, **39*B***, 427) considered that the type of product depended on which bromine atom was the more labile; this would be eliminated as hydrogen bromide before the acetoxy-group was hydrolysed:



(1)

(II)

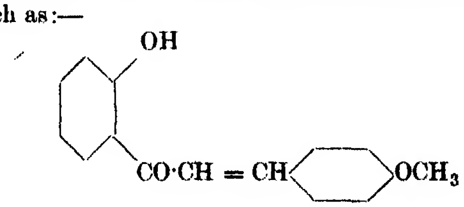
They do not seem to have been aware of the work of Auwers and Anschütz on the free hydroxy-compounds.

Cullinane and Philpott (*J.C.S.*, 1929, 1761) pointed out that when chalkones derived from phloroglucinol were brominated, the bromine also entered the phloroglucinol nucleus, and suggested that this bromine atom favoured the production of benzylidenecoumaranones.

The object of the work outlined below was to find if possible the reason for the dual course of the reaction, and then so to modify the conditions of the reaction as to make it suitable for the synthesis of naturally-occurring flavones; apart from its uncertainty the reaction has advantages in that chalkones are, as a rule, easily obtained, and the flavones when produced are formed in satisfactory yield.

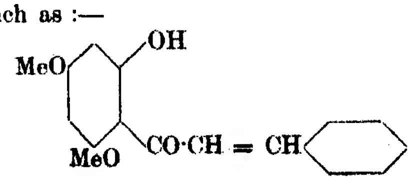
Preliminary to the investigation, a survey of the literature showed that the chalkone dibromides which gave benzylidenecoumaranones rather than flavones could be divided into two classes:—

(*a*) Those derived from *o*-hydroxyphenyl *p*-alkoxystyryl ketones (III) such as:—



(III)

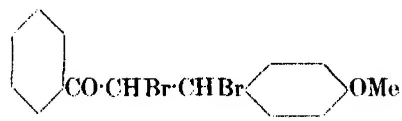
(*b*) those derived from 2-hydroxy-4 : 6-dialkoxyphenyl styryl ketones (IV) such as :—



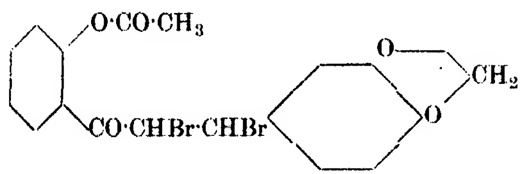
(IV)

We will consider the two cases separately.[1]

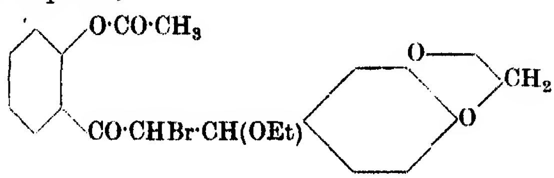
Chalkones dibromides derived from o-*hydroxyphenyl* p-*alkoxystyryl ketones.* Nearly 40 years ago when Kostanecki was abandoning the chalkone dibromide reaction for the synthesis of flavones, Pond and Shoffstall (*J. Amer. Chem. Soc.*, 1900, **22**, 658) showed that one of the bromine atoms in phenyl *p*-methoxystyryl ketone dibromide



is labile and can be replaced by alkoxyl on boiling with an alcohol. They were incorrect in the view that it is the bromine nearer the keto-group which is replaceable; various reasons can be adduced to show that it is the halogen atom next the alkoxyphenyl nucleus that is labile (Dodwadmath and Wheeler, *Proc. Ind. Acad. Sci.*, 1935, **2**, 439), the simplest being that the nucleus containing the activating alkoxy-group may be expected to influence the nearer halogen atom. Nadkarni, Warriar and Wheeler (*J.C.S.*, 1937, 1798) showed that the production of benzylidenecoumaranones in place of flavones from *o*-hydroxy- or *o*-acetoxy-aryl *p*-alkoxystyryl ketone dibromides depends on whether or no a β-alkoxy-compound is formed. They found that *o*-acetoxy phenyl $\alpha\beta$-dibromo-β-3 : 4-methylenedioxyphenylethyl ketone,

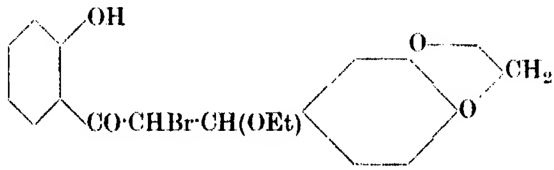


gave 3′ : 4′-methylenedioxyflavone: (*a*) on direct heating, (*b*) with hot pyridine, (*c*) with hot or cold aqueous sodium hydroxide containing acetone, and (*d*) with cold aqueous alcoholic sodium hydroxide (Auwers and Anschütz, *loc. cit.*) or sodium carbonate: with (*e*) hot aqueous alcoholic sodium hydroxide (Feuerstein and Kostanecki, *Ber.*, 1899, **32**, 316) or carbonate, the 3′ : 4′-methylenedioxy benzylidenecoumaranone is obtained; intermediate formation of the ethoxy-compound,



[1] Price and Bogert (*J. Amer. Chem. Soc.*, 1934, **56**, 2442) have found that the dibromides derived from 2-hydroxy-3 : 4-dimethoxyphenyl *o*-, *m*- and *p*-nitrostyryl ketones also belong to Class (*b*).

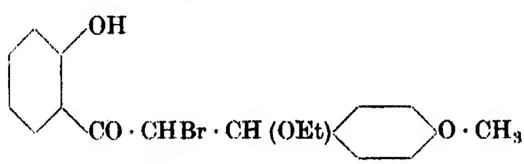
is to be expected with hot alcohol, but not readily in the cold. *o*-Hydroxyphenyl $\alpha\beta$-dibromo-β-3 : 4-methylenedioxyphenylethyl ketone gave similar results, except that with hot pyridine no definite product was obtained. *o*-Hydroxyphenyl α-bromo-β-ethoxy-β-3 : 4-methylenedioxyphenylethyl ketone,



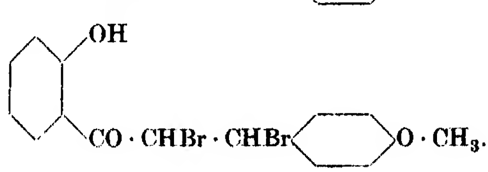
on being heated above the m.p. or with pyridine gave the flavone; with sodium hydroxide or sodium carbonate in hot or cold acetone or alcohol the benzylidenecoumaranone was obtained. Once the ethoxy-compound is formed, neither alcohol nor heat is necessary for the production of benzylidenecoumaranone; all that is required is that sodium hydroxide or sodium carbonate shall be present.

Further work in this laboratory (S. N. Rao and R. K. Kamat) has shown that a *p*-benzyloxy-group in the styryl nucleus of a chalkone dibromide also renders labile the neighbouring bromine atom, so that an ethoxy-compound is readily formed with alcohol; with alkali this ethoxy-compound gives the benzylidenecoumaranone.

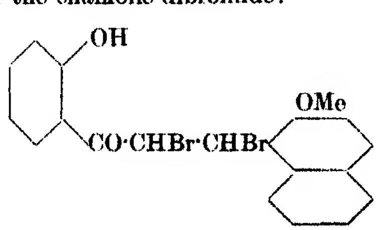
It has recently been found here (M. Samiulla, W. A. Hutchins and S. N. Rao) that with alcoholic potassium cyanide, the flavone is at once obtained from compounds of the type



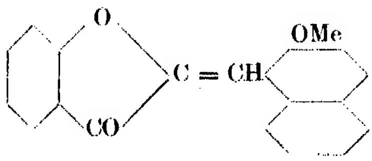
and



It has also been shown (B. G. Acharya) that the *o*-alkoxy-group in the benzostyryl nucleus of the chalkone dibromide:—



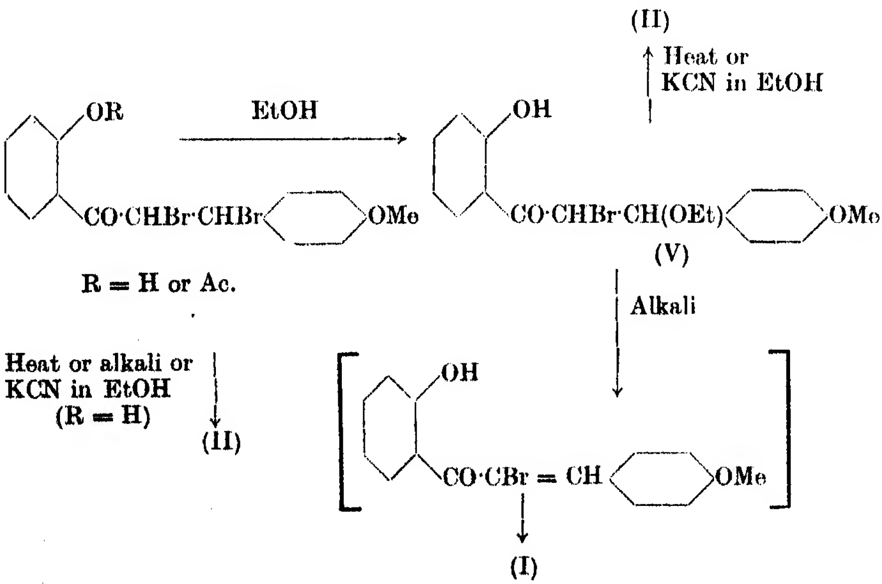
also energises the nearer bromine atom, and that the ethoxy-compound which can be obtained with alcohol gives rise to benzoflavones with alcoholic potassium cyanide, and to naphthylidenecoumaranones of the type



with alcoholic alkali. It may be mentioned that it has been shown (N. A. Bhagwat) that the bromine atom in *p*-alkoxy-styryl compounds is more labile than in the *o*-alkoxy-compounds; alkoxyl in the *m*-position has no activating effect (cf., Bauer and Vogel, *J. pr. Chem.*, 1913, **88**, 329). The presence of a nitro-group in the alkoxy-styryl nucleus renders the bromine inactive (Dodwadmath and Wheeler, *loc. cit.*); the chlorine in chalkone dichlorides is less active than the bromine in dibromides.

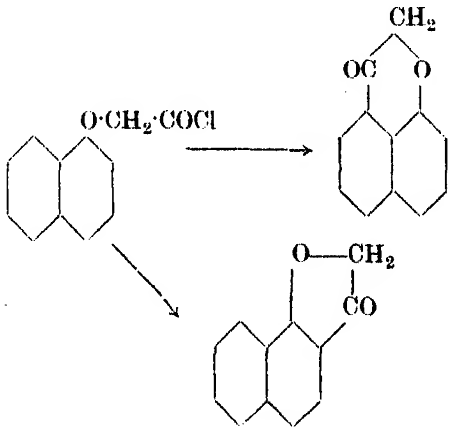
This theory it will be seen not only explains the observation of Auwers and Anschütz that working in the cold favours the formation of flavones, but also their discovery that some dibromides under all conditions give flavones only; if there be no activating alkoxyl group in the styryl nucleus, there is no possibility of formation of an alkoxyl compound with alcohol.

We may write, therefore,



It is known that the bromoethoxy-compounds of the type (V) readily eliminate a molecule of alcohol to form an α-bromochalkone (see for example, Nadkarni, Warriar and Wheeler, *loc. cit.*) which with alkali will give the benzylidenecoumaranone (Kostanecki and Tambor, *Ber.*, 1899, **32**, 2267). An apparent exception to this view is afforded by the *o*-hydroxynaphthyl *p*-alkoxystyryl ketone dibromides which yield flavones with hot alcoholic alkali (Kostanecki, *Ber.*, 1898, **31**, 708). This anomalous result has been traced (A. P. Khanolkar and G. V. Deshmukh) to the fact that these dibromides are not readily soluble in hot alcohol so that the formation of the ethoxy-compound is slow. If the solubility of the dibromide is increased by addition of chloroform, ethoxy-compounds which give benzylidenebenzocoumaranones with alcoholic alkali are readily obtained.

The use of the ethoxy-bromides provides a certain synthesis of benzylidenecoumaranones. It may be noted that the method employed by Ingham, Stephen and Timpe (*J.C.S.*, 1931, 895), for the synthesis of benzocoumaranones from α-naphthyloxyacetyl chlorides is ambiguous, and can give rise to either of two compounds as shown:—

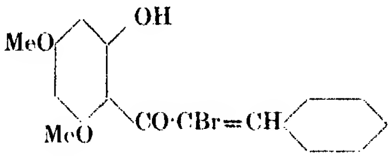


These compounds can be condensed with aldehydes to give benzylidene derivatives.

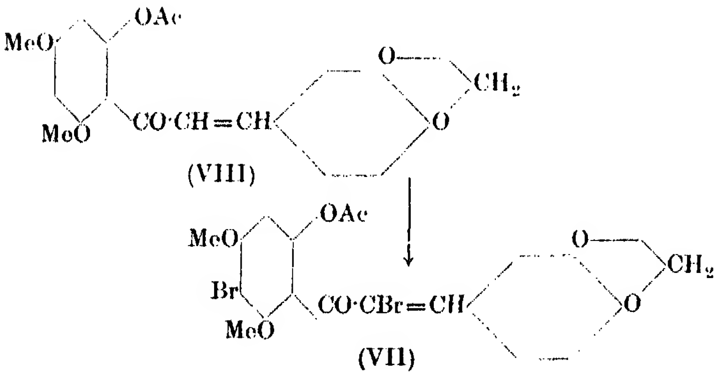
It will be clear, therefore, that a flavone can always be obtained from an *o*-hydroxyphenyl alkoxystyryl dibromide by working without alcohol, so as to prevent the formation of an ethoxy-compound. Direct heating will also give the flavone. A better method, however, is to use potassium cyanide and alcohol; this gives the flavone even though the ethoxy compound be formed.

Chalkone dibromides from dialkylphloroacetphenone chalkones. Chalkone dibromides derived from (IV) are known to give benzylidenecoumaranones

with hot or cold alkali (Cullinane and Philpott, *loc. cit.*), and this has precluded the synthesis by the method under investigation of some important naturally occurring 5 : 7-dihydroxyflavones. The course of the reaction is here to be referred to the fact that the bromine atom β to the keto-group is readily eliminated as hydrogen bromide to form an α-bromochalkone (VI) and, in fact, Kostanecki and Tambor (*loc. cit.*) obtained (VII) directly by bromination of (VIII).



(VI)

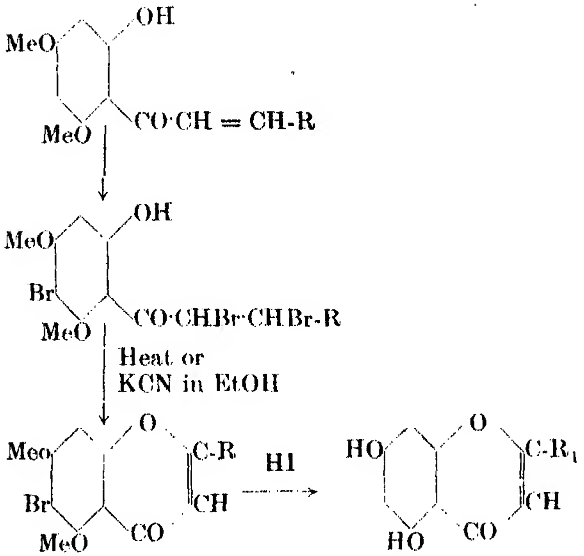


(VIII)

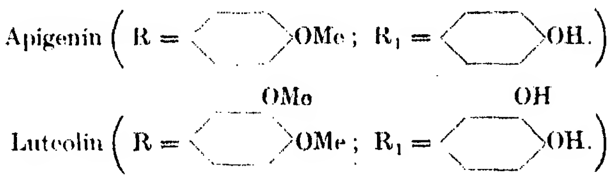
(VII)

A variety of experiments, however, showed, that when 2-hydroxy-4 : 6-dimethoxyphenyl styryl ketone dibromides were heated above the melting point or better in alcoholic solution with potassium cyanide the corresponding flavone was obtained. Hot or cold alkali even in the absence of alcohol yielded the benzylidenecoumaranone.

Synthesis of some naturally-occurring flavones: (W. H. Hutchins). Many naturally-occurring flavones require for their synthesis chalkone dibromides falling within both of the above classes; that is 2-hydroxy-4 : 6-dimethoxyphenyl p-alkoxystyryl ketone dibromides. However, the observation that heat or the action of potassium cyanide in alcoholic solution produces flavones from both types of dibromides has enabled the three naturally-occurring flavones, chrysin, apigenin and luteolin to be synthesised by the following series of reactions:—



Chrysin (R = Ph ; R_1 = Ph).



For details of some of the work described above see :—*Proc. Ind. Acad. Sci.*, 1935, 2, 439 ; *J. Univ. Bombay*, 1937, *6*, 107 ; *J.C.S.*, 1937, 1737, 1798 ; 1938, 1320, 2118 ; 1939, 91, 94, 96.

ON THE BURROWING HABITS OF A GOBIOID FISH OF THE GENUS *TAENIOIDES* IN THE ANDAMANS.[1]

By H. SRINIVASA RAO, *M.A., D.Sc., F.A.Sc., F.N.I., Zoological Survey of India, Calcutta.*

(Published with the permission of the Director, Zoological Survey of India.)

(*Read April 5, 1939.*)

In the course of his recent studies on the ecology and bionomics of the Gobioid fishes of the Gangetic delta Hora[2] (1935, 1936) briefly dealt with the burrowing habits of certain species. While stationed in Port Blair, Andamans, during the years, 1932 to 1935, I had an opportunity of observing the burrowing habits of two species of Muraenid and Gobioid fishes living in the mud flats at the entrance to certain brackishwater creeks in the vicinity of Port Blair. My stray notes on this subject are offered in the present communication as a supplement to Hora's published observations.

While digging in the mud for worms and other organisms near the edge of a creek at South Corbyn's Cove, Port Blair, I found, in addition to several specimens of a Muraenid eel, a few examples of a Gobioid fish of the genus *Taenioides* not more than four inches in length. In life, they were of a pinkish brown ground colour with golden yellow blotches on the sides. As this Goby lived in fairly deep burrows and observation of living examples in their natural habitat was impossible, a few specimens were taken alive to the Fisheries Laboratory where they were kept in aquaria for further observation. Soft mud from the creek was placed at the bottom of a large aquarium jar and sea water was added to a height of about 6 inches above the surface of the mud. When the live specimens of *Taenioides* were dropped into the jar, they explored the bottom for 5–10 minutes, presumably, to find a suitable place for burrowing, and then shovelled up the mud with their head to make burrows. Where the mud was soft the process of burrowing was fairly quick, a burrow 6–8 inches long taking only 10–15 minutes to make. Where the mud was hard the fish actually bit off lumps of mud with their long sharp teeth and

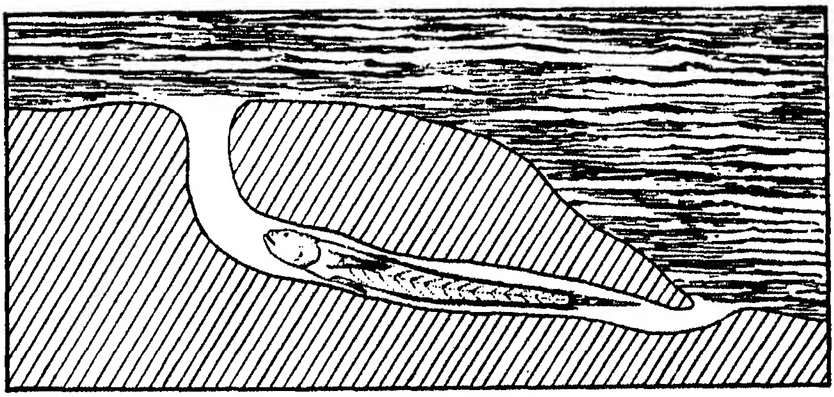
---

[1] The specimens of fish used in the experiments which form the subject matter of this note are immature forms and are consequently difficult to identify. In dentition they agree with the description of *Taenioides cirratus* (Blyth) but seem to differ from it in body proportions. It is likely that the specimens represent the young of *T. caeculus* (Bl. & Schn.), a species recorded by Day from the Andamans.

[2] Hora, S. L. *Trans. Nat. Inst. Sci. India*, 1, p. 9, pl. i, fig. 2, (1935).
Compt. Rend. XII Congr. Internat. Zool. Lisbonne, 1935, pp. 854, 855, pl. xlvi, fig. 5, (1936).

ejected them rapidly through the opercular openings.[1] In this manner a burrow was completed in about 15 minutes. The loose mud that was falling from the sides in the process of burrowing was thrown out from the burrow by the vigorous motion of the operculum, the fins, and the posterior part of the body of the fish. The meandrine lamellar ridges on the dorsal surface of the head, on the cheek, and on the sides of the body up to the caudal fin presumably facilitate the process of burrowing by acting as effective shovels.

The burrow may be a simple tunnel of more or less uniform calibre running obliquely as in Text-fig. 1 and opening on the surface of the mud at the same

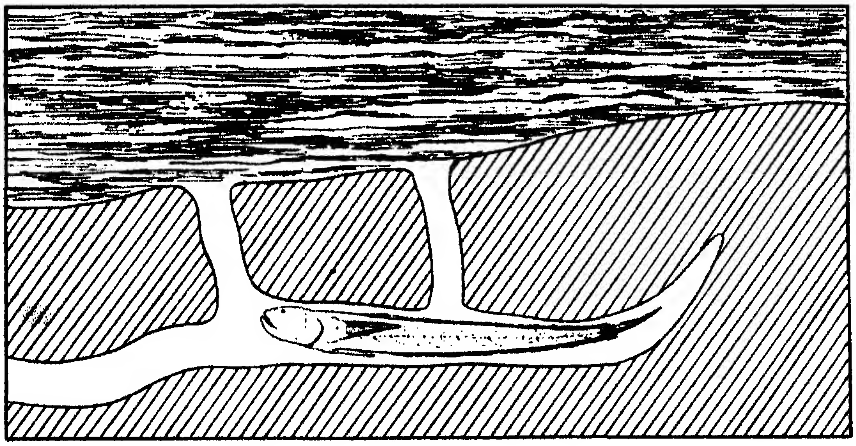


TEXT-FIG. 1.—A simple burrow of *Taenioides* with the two openings at different levels of the bottom.

or different levels by two rounded apertures. The fish takes up a position in the middle of the burrow where it is concealed from view. The burrow may end blindly at one end and lie horizontally some distance below the surface, and often in communication with the exterior by additional vertical tunnels as in Text-fig. 2. The egress and ingress of the fish is thus greatly facilitated. In this instance it is not known whether the inhabitant of the horizontal burrow has made the vertical tunnels or some other fish trying to burrow in the close vicinity has chanced to cut across the horizontal burrow. A slight variant of the type of burrow described above may be seen in Text-fig. 3 where the horizontal burrows are slightly curved communicating as usual with the exterior by vertical tunnels. Burrows of different calibres,

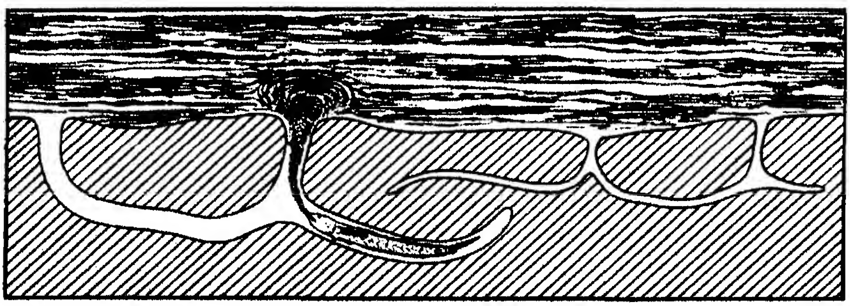
[1] Dr. Hora (1936) observed in *T. rubicundus* that when the mud provided was hard the fish had to bite off large lumps which they 'coughed' out by mouth. In the species observed by me of which I had only small specimens the particles of mud bitten off were ejected forcibly through the gill-openings which are large enough for the passage of the particles of mud. The gill-rakers in this process seem to be adpressed to the walls of the gill-chamber when expanded and thus facilitate the passage of the particles without hindering the function of the gills.

presumably belonging to two different sizes of fish may be seen in this figure. A complicately branched burrow as in Text-fig. 4 with vertical tunnels of



TEXT-FIG. 2.—A horizontal burrow of *Taenioides* ending blindly at one end, and with two vertical connecting burrows of narrower calibre leading to the outside.

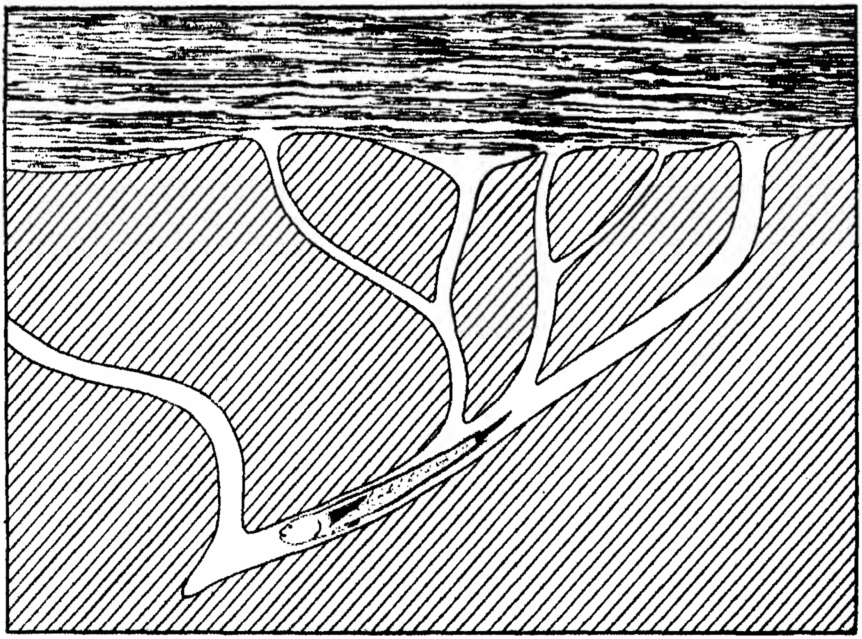
varying calibre has also been observed in the Laboratory. I have not observed more than one fish in these burrows and their connected tunnels, and am



TEXT-FIG. 3.—Burrows of *Taenioides* of narrow calibre communicating with the outside by means of short vertical shafts. The fish in one of the burrows is expelling a cloud of mud to keep the burrow open and clean.

consequently unable to say whether the burrows of different calibres are made by fish of different sizes. The occlusion of the vertical tunnels by falling particles of mud is fairly common, and I have observed fish repairing damage to their burrows by throwing out forcibly the particles of mud dropping into them in a cloud that may frequently be observed at the mouth of the burrows (Text-fig. 3).

The fish usually take up convenient positions in the horizontal portions of the burrows, and by vigorous movements of the gill-operculum and of the body maintain an inward respiratory current of water flowing through the tunnels and bringing with it minute particles of organic and inorganic matter. The respiratory movements of the gill-operculum are about sixty to the minute.



TEXT-FIG. 4.—A deeper and more complicated burrow of *Taenioides* communicating with the outside by subsidiary burrows of narrower calibre.

The fish, however, rest at short intervals stopping all movements. Occasionally, in the course of the day, but more often at night, the fish emerge from their burrows to the surface of the bottom mud, swim about a little in the upper layers of water and finally return to their burrows. The junction of the vertical and the horizontal portions of the burrows is often utilized by the fish to reverse the direction in which they lie in the burrows. The forcible ejection of water and solid particles by mouth assisted by the undulatory movements of the body in a postero-anterior direction referred to above is, however, an infrequent phenomenon, but the backward and forward movements of the fish in their burrows are more frequent and are suited to the needs of the fish. When the inward respiratory current is set up, the movements of the body of the fish are slow and rhythmical, and a gentle current of water enters the burrow by the opening nearest to the anterior end of the fish and leaves it at the other end of the burrow nearest to the tail-end of the fish.

The more violent expiratory currents are caused by the rapid undulatory movements of the body in a reverse direction and by the forcible expulsion of water through the mouth.

The capacity of the fish to burrow in pure sand or in a mixture of sand and mud was tested in another experiment. An aquarium jar was filled with sand to a fourth of its height and filled with sea water. Two specimens of the *Taenioides* were introduced into the jar. Failing in the repeated attempts to burrow in the sand at intervals of every few minutes, the fish kept on swimming along the sides of the jar, often sticking to the surface of the glass by the ventral fins, and finally settled down on the surface of the sand more or less exhausted. In a well-mixed mixture of equal parts of soft mud and sand, the fish were at first unsuccessful in making burrows, but several hours later they were found inside burrows in the sand and mud mixture.

The behaviour of the Muraenid eels captured in the same locality as *Taenioides* was, however, different in the aquarium. The moment they were introduced into the aquarium consisting of sand, mud, or a mixture of both, they took a straight plunge into the bottom disappearing into burrows made instantly with their sharp pointed snout in less than a minute. They, however, returned now and again to the mouth of the burrow keeping their head well above the surface of the substratum and continuing the respiratory movements of their operculum.

When the bottom mud in the aquarium was only just kept moist, the Muraenid eel often came to the mouth of the burrow, while *Taenioides* never once left the burrow.

Of the three specimens of *Taenioides* one lived in the Laboratory aquaria for 47 days, while the other two lived for 58 days.

I have to thank my friend, Dr. S. L. Hora, for suggestions in writing up this note.

Discussion.

On being invited by the President to make some remarks on Dr. H. S. Rao's illuminating paper, Dr. Hora referred to the observations made by him on the burrowing habits of the Gobioid fishes of the Gangetic Delta. Attention was particularly directed to the suitability of the soft and colloidal mud of the estuaries for making burrows. The various advantages derived by the fish by living in burrows were referred to, and mention was made of parallelism in form between the diverse types of burrowing animals, such as snakes, eels, gobies, etc.

PHYSIOLOGY OF RESPIRATION AND EVOLUTION OF AIR-BREATHING FISHES.[1]

By SUNDER LAL HORA, *D.Sc.*, *F.R.S.E.*, *F.N.I.*, *Assistant Superintendent, Zoological Survey of India, Calcutta.*

(*Read April 5, 1939.*)

In 1935, I published the results of a series of experiments and observations on the bionomics and physiology of respiration of certain air-breathing fishes of India, and after reviewing the earlier literature on the subject concluded that

> 'provided suitable physiological conditions are established, the majority of the air-breathing fishes can live under water almost indefinitely'.

As a result of these experiments it also became clear that some of the so-called organs of aerial respiration may originally have developed for increasing the area for aquatic respiration, and later, under adverse conditions of stagnation and drought, through 'Change of Function', became adapted for aerial respiration. This is evident in the case of a number of estuarine gobies, eels, etc., in which, at the time of aerial respiration, the air is stored up in lateral pouches of the buccal cavity, and also in some torrential and marine fishes in which similar arrangements for aerial respiration exist. During aquatic respiration, when the buccal cavities are filled with water, their internal respiratory lining, which is continuously bathed by water, no doubt subserves aquatic respiration. This simple, but widely employed, mode of aerial respiration was undoubtedly preceded by the habit of breathing air continuously, as observed in the Mastacembelidæ, *Mystus gulio*, *Stigmatogobius sadanundio*, and many other fishes of tropical fresh waters; in the latter process an almost continuous respiratory current of air is passed through the buccal cavity and over the gills.

Of the Indian species provided with special organs of aerial respiration, the air-chambers of *Amphipnous*, though capable of performing aquatic respiration for a relatively much shorter period, are too small and highly specialized to carry on this function for any length of time, especially as the gills of this fish are greatly reduced. Thus among the Indian fishes adapted for aerial respiration *Amphipnous cuchia* is probably the only species that cannot perform aquatic respiration effectively for any length of time even when kept in thoroughly aerated waters. In this respect it is more terrestrial than *Periophthalmus* and other well-known terrestrial fishes of the tropics. Its organs of aerial respiration are, however, perfect as the fish can live in water

[1] Published with the permission of the Director, Zoological Survey of India.

VOL. V—No. 2. [Published 13th July, 1939.

totally devoid of oxygen or even that artificially saturated with CO_2 (*vide* Das, 1927, p. 209).

The long tubes of *Heteropneustes* were found to be free from water even when the fish was kept immersed for several days and, in fact, the tubes seem to have been specialized to carry out aerial respiration only; the gills of the fish are probably of normal dimensions, and there can be no doubt that they are sufficient to sustain life by means of aquatic respiration, provided physiological conditions are suitable. Thus in *Heteropneustes* we have a high degree of differentiation between the organs of aquatic and aerial respiration. Each type seems to be independent of the other and is probably sufficient by itself to maintain the normal activities of the fish when called upon to do so. I have shown in my experiments that the gills are quite effective for aquatic respiration under suitable physiological conditions, while the air-tubes were found by Das (1927, p. 209) to be insufficient to sustain life for more than 6 hours or so when the fish were kept either in boiled water or in water through which CO_2 was being bubbled.

In *Clarias*, both the gills and the dendritic growths for aerial respiration are bathed in water when the fish is kept under water and is not allowed access to atmospheric air. In this Siluroid fish, therefore, there is no rigid division of labour among the two types of respiratory organs. In the case of *Clarias* also Das found that the organs of aerial respiration could not by themselves sustain the life of the fish for more than 6 to 8 hours.

In *Ophicephalus* and the labyrinthine fishes, such as *Anabas*, in which the air-cavities are dorsal, if the cavities are not evacuated of the air contained in them, the fish cannot exist on aquatic respiration through the gills alone, but if the cavities are emptied, so that the respiratory current of water can wash their inner lining, the increased respiratory area thus made available was experimentally found to be sufficient for the fish to exist on aquatic respiration alone. Further, it was found by Das (1927, p. 209) that the organs of aerial respiration of these fishes were not by themselves sufficient to maintain life for more than 6 to 8 hours. In the case of these fishes, therefore, under natural conditions the aerial and aquatic organs of respiration would seem to be dependent on one another for maintaining the life of the fish.

From the above it will be clear that, according to their respective requirements, various types of fishes have undergone diverse modifications, and for this reason it appeared to me that:

> 'The habit of breathing air seems to have been acquired independently by groups of species living under different environmental conditions, and it seems evident that while the simplicity of a structure is no criterion of its low organization or primitive nature, its utility appears to be the sole guiding principle in its evolution.'

In my (1935) article, I referred to Das's 'drowning' experiments in which he used *water saturated with oxygen from a generator*, and found that '*Anabas, Clarias, Saccobranchus, Ophiocephalus*' succumbed in periods of 3 to 8 hours. I attributed the death of *Anabas* and *Ophicephalus* to the cavities being probably

filled with air, when the fish was kept under water, but I failed to account for the death of *Clarias* and *Heteropneustes* (=*Saccobranchus*) in his experiments. Das (1937), in a recent article, has reiterated his results and views and has not only criticised my deductions, but even doubted the findings of my experiments without trying to verify my results by carrying out experiments, either in accordance with the technique fully explained in my article or that employed by Ghosh (1934). It must be understood that my experiments, with somewhat improved technique, were only a corollary to those of Ghosh.

On a careful perusal of Das's papers on air-breathing fishes, the only difference that I find between the technique employed by him and myself in 'drowning' experiments was that he oxygenated the water whereas I aerated the water, and it was primarily to test whether this difference in the technique could account for the great difference in our results that the following experiments were undertaken.

'Drowning' experiments were carried out with *Clarias* and *Heteropneustes* in the laboratory of the School of Tropical Medicine under the supervision of its Director, Col. R. N. Chopra, a distinguished physiologist. The specimens were kept in two jars, through one of which the air was being pumped, while through the other oxygen was being passed from a cylinder; the fish were prevented access to atmospheric air by means of a wire gauze diaphragm. All the specimens were found to be quite healthy even after 24 hours when the experiment was discontinued. Even when boiled water saturated with oxygen from a cylinder was used the fish showed no signs of excitement during the five hours, for which the experiment was in progress. On an enquiry being made about the effect of excess of oxygen on respiration, Col. Chopra very kindly wrote to me as follows concerning its action on warm-blooded animals:—

> 'Oxygen constitutes about 1/5 (20·94 per cent) by volume of ordinary air. An increase of this proportion and even an inhalation of undiluted oxygen produces no noticeable effect under ordinary conditions. The rate of oxidation or the consumption of oxygen is not at all increased; indeed the output of CO_2 is rather lessened. Evidently the proportion of oxygen in air suffices for all ordinary needs, and additional oxygen acts merely as an indifferent gas—as so much nitrogen or hydrogen. Oxygen under excessive pressure, about 3 or 4 atmospheres, however, causes violent convulsions and ultimately death.
>
> 'The role of nitrogen is practically inert, it acts as a diluent only.'

Thus failing to achieve the results obtained by Das, even after using highly oxygenated water, I wrote to him the following letter, dated the 12th July, 1938:—

> 'I perused your article on air-breathing fishes, which was read at the Lisbon meeting of the International Congress of Zoology, some months ago, but did not want to publish a rejoinder till I had an opportunity to repeat my experiments once again. I have done so now and the experiments were carried out in the Physiological Laboratory of the School of Tropical Medicine under the supervision of India's greatest physiologist, Colonel R. N. Chopra. So long as the water was kept thoroughly

aerated or oxygenated *Magur* and *Singi* did not die even when prevented access to air for 24 or more hours. As a full account of the technique employed by you in your "drowning" experiments is not available in your papers, may I have some of the necessary details to repeat your experiments so as to arrive at some definite conclusions. I do not for a moment doubt the results of your experiments, but I believe there must be some fundamental difference in the way we have carried out our experiments. As I have published full details of the technique employed by me, may I request that you should also repeat my experiments to find out the truth for yourself.

'It will be in the interest of scientific progress that no doubt should be left regarding the validity of our experimental data. It is immaterial if we differ in the interpretation of the data.'

To the above Prof. B. K. Das replied (dated, the 17th July, 1938) as follows:—

'Many thanks for your D.O. No. 3265 dated July 12th, 1938. I am fully satisfied that my experiments and their results are quite correct and convincing.'

In view of Professor B. K. Das's reply I am unable to account for the difference in our results and have now no course open to me except to reiterate my previous views, based as they are on experimental data which have been fully confirmed by a series of recent experiments as indicated above. A careful study of Prof. Das's earlier paper (1927) has shown that he himself has not paid sufficient attention to the significance of his experiments with boiled water (p. 209), and water saturated with carbon dioxide (p. 210). When he used boiled water, from which the dissolved oxygen had been expelled, he found that specimens of *Clarias*, *Heteropneustes*, *Anabas*, *Ophicephalus* and *Amphipnous* when kept in jars filled with this water:

'At first these fish behaved normally, but soon become extremely agitated and snapped for air with increased frequency. *Clarias*, *Saccobranchus* and *Anabas* survived for 6 hours, then made convulsive movements and died; *Ophicephalus* survived for 8 hours, but *Amphipnous* after three days appeared to be in quite a healthy condition. As controls water-breathing fish were subjected to the same condition. In all branchial movements were suspended in 2 to 5 minutes, and in every case death occurred in half an hour.'

When he used water saturated with CO_2 gas, he found that the same species of air-breathing fish, *Anabas*, *Clarias*, *Heteropneustes*, *Ophicephalus*, when placed in water through which a stream of CO_2 bubbles was kept passing:

'At first some fish snapped [1] at these bubbles, but later inhaling them became excited and fled to the farthest corner of the aquarium, where they vigorously and rapidly inhaled air. All came to the surface in less than an hour, and all succumbed in less than 6 hours. When kept below a diaphragm they were "drowned" in 45 minutes. Control water-breathing fish under similar circumstances all came to the top in 5 minutes and died within half an hour.'

The above statements are significant in so far as they show that, with the exception of *Amphipnous*, the so-called air-breathing fishes of India cannot

[1] In my experiments I did not notice the fish snapping either at the bubbles of air or at the bubbles of oxygen.

exist on aerial respiration alone; in the economy of their lives aquatic respiration also plays a very vital part. One or the other mode of respiration may predominate at times according to the physical conditions of their respective environments, but under natural conditions a combination of the two seems to be essential. In my experiments it was found that, with the exception of *Amphipnous*, all other types of Indian air-breathing fishes could exist on aquatic respiration for an almost indefinite period, and since Das found that they, again with the exception of *Amphipnous*, could not live on aerial respiration alone, there would seem to be considerable justification for believing that in fishes, as a rule, the aerial mode of respiration was resorted to in its earlier stages of evolution only as an aid to the aquatic respiration of the species. This is certainly true of a great majority of tropical fresh-water fishes even at the present day when on hot days they come to the surface and gulp in air which is passed over the gills. Further, it is a commonplace observation that the frequency of the visits of the majority of air-breathing fishes to the surface for inhaling atmospheric air depends upon the quality of the water; the visits are more frequent if the water is stagnant and foul, and less frequent if it is clear and aerated. This also shows that aerial respiration is only resorted to when aquatic respiration proves insufficient for the requirements of these fishes. *Amphipnous*, among the air-breathing fishes of India is, however, an exception as indicated above.

Reference may also be made to data that have come to my knowledge since the publication of my article referred to above.

As early as 1915, Howell published 'Notes on the Respiration of the Murral (Ophiocephalidæ)' and showed the effect of low temperature and of running water on the aerial respiration of the fish. From his observations he concluded that:

> 'the air cavity is only an auxiliary apparatus to be called into use when the supply of oxygen obtained through the gills is insufficient.'

The above view fully confirms my observations on the physiology of respiration of the so-called air-breathing fishes of India.

A student of the Bombay University performed 'drowning' experiments on *Periophthalmus*. His results are not yet published but as an examiner of his thesis, I have had an opportunity of reading them. He found that if the sea water was kept properly aerated *Periophthalmus*, the most terrestrial of our fishes, can be made to live under water and subsist on aquatic respiration alone, thus confirming my experiments on *Periophthalmodon*. Attention may also be directed to Rao's (1938, pp. 386–389) experiments on the aerial and aquatic respiration of the marine Blenny *Andamia*.

Owing to the discrepancies in the results of Prof. B. K. Das's 'drowning' experiments and those performed by me it seems desirable that other workers interested in the subject should repeat these experiments and report the results. The experiments are very simple and can be carried out easily with

Clarias and *Heteropneustes*. Where aerating of water with the help of a pump is not possible a continuous stream of water should be allowed to flow through the basin in which the fish are kept under a diaphragm (*vide* Hora, 1935, pl. i, fig. 7.).

LITERATURE.

Das, B. K.—The Bionomics of Certain Air-Breathing Fishes of India, together with an account of the Development of their Air-Breathing Organs. *Phil. Trans. Roy. Soc. London* (B), Vol. 216, pp. 183–219, 9 pls. (1927).

Das, B. K.—On Ecology and Bionomics of an Air-breathing Loach '*Lepidocephalus guntea*' (Ham. Buch.), with a Review on Air-breathing Fishes. *Comptes Rendus*, XII *Congr. Internat. Zool.*, Vol. 2, pp. 866–920, 3 pls. (1937).

Ghosh, E.—An Experimental Study of the Asphyxiation of some Air-breathing Fishes of Bengal. *Journ. As. Soc. Bengal*, (N.S.), Vol. 29, pp. 327–332, 1933 (1934).

Hora, S. L.—Physiology, Bionomics, and Evolution of the Air-breathing Fishes of India. *Trans. Nat. Inst. Sci. India*, Vol. 1, pp. 1–16, 1 pl. (1935).

Howell, G. C. L.—Notes on the Respiration of the Murral (Ophiocephalidæ). *Journ. Bombay Nat. Hist. Soc.*, Vol. 34, pp. 195, 196 (1915).

Rao, H. S. and Hora, S. L.—On the Ecology, Bionomics and Systematics of the Blennid Fishes of the genus *Andamia* Blyth. (Ecology and Bionomics *by* H. S. Rao). *Rec. Ind. Mus.*, Vol. 40, pp. 386–389 (1938).

SUMMARY.

The author gives a brief résumé of the results obtained in his earlier experiments on the 'drowning' of the so-called air-breathing fishes of India. In view of Das's recent criticism of his data the author has repeated the experiments in the laboratory of the School of Tropical Medicine under the supervision of Col. R. N. Chopra. Recent experiments were carried out with thoroughly aerated and oxygenated waters. Finding no difference in the results, he wrote to Prof. B. K. Das about the technique employed by him, but did not get a helpful reply. Consequently, the author reiterates his views and in their support adduces fresh experimental evidence that has come to his knowledge since the publication of his first paper in 1935. Finally the author requests other workers in India to repeat the experiments with a view to clarifying the different results obtained by different authors.

DISCUSSION.

Before declaring the paper open for discussion the *President* thanked the author for the interesting results obtained by him and remarked that he closely watched the progress of the so-called 'drowning' experiments on *Magur* and *Singi* performed by Dr. Hora in his laboratories. He was thus in a position to state that the fish when kept in thoroughly aerated or oxygenated water and prevented by a diaphragm from coming to the surface continued to live for long periods without showing any signs of distress. Even when oxygen from a cylinder was bubbled through, the fish did not evince any excitement. It is unfortunate that Prof. B. K. Das has not helped Dr. Hora to repeat the

experiments with his technique, but it may be hoped that other workers interested in the subject will repeat Dr. Hora's experiments to convince themselves of the data presented in his papers.

Professor *J. N. Mukherjee* wanted to know whether in Dr. Hora's experimental arrangement the possibility of minute bubbles of air, not visible to the naked eye, was excluded. He suggested that an arrangement excluding this possibility might be tried and oxygen contents of water at different places might be determined.

Dr. *P. Neogi* suggested that the presence of excess of oxygen, especially under pressure, might have exercised an asphyxiating influence on the fishes, for they might have died as a result of it just as a candle will burn out very quickly if oxygen is substituted for air as the medium of combustion.

Dr. *R. B. Lal* observed that the problem as he understood was whether in Dr. Hora's experiments the oxygen was given in gaseous state to the fish or whether it was a question of the amount of the dissolved air. If the latter be the case, then the ordinary aquatic fishes also require a certain amount of dissolved air and the question arises whether in the experiment of the two workers the partial pressure of oxygen was equally suitable for the terrestrial fishes.

Dr. *H. S. Rao* remarked that as only a limited amount of oxygen or air can be dissolved in a given quantity of water at a certain temperature the continuous bubbling of the gas can have no harmful effect on fishes; the excess of the gas would not be dissolved in the water, but would be passed out as such.

The *President* explained that, judging from the data available from our knowledge of human physiology, excess of oxygen under normal pressure has no adverse effect on respiration, but if the pressure is increased even three to four times then the excess of oxygen causes violent convulsions and may ultimately result in death. He presumed that the same physiological laws would probably apply in the case of fish also.

In reply to Prof. J. N. Mukherjee Dr. *Hora* stated that as in Prof. Das's and his experiments the gas was bubbled through the presence of minute bubbles of air in water could not account for the differences in their respective results. Moreover, he directed attention to the series of 'drowning' experiments carried out by him in 1934 in which he had arranged a continuous supply of fresh water from a tap. In reply to others, Dr. Hora stated that the water containing the fish and through which air from a pump or oxygen from a cylinder was bubbled was kept at ordinary pressure, and in view of Col. Chopra's observations the oxygen content of water could not have adversely affected the fishes. In any case until Prof. Das fully explains the technique employed by him it will be difficult to verify the results obtained by him.

The President concluded the discussion by remarking that it will be useful if in any future experiments the oxygen contents of water, as suggested by Prof. J. N. Mukherjee, were also determined.

STRUCTURE AND DEVELOPMENT OF THE EMBRYO-SAC OF *IPHIGENIA INDICA* KUNTH.

By A. C. Joshi, *D.Sc., Department of Botany, Benares Hindu University.*

(*Read April 5, 1939.*)

Although the family Liliaceæ has been a favourite subject for cytological and embryological studies for a long time and a vast amount of literature has accumulated on the subject, still our knowledge is far from complete. Many tribes and sub-tribes still remain to be investigated. Thus not even one member of the tribe Iphigeneæ of Hutchinson (1934), which includes the genera *Orinthoglossum*, *Iphigenia*, *Camptorrhiza*, *Reya* and *Androcymbium*, distributed over Africa, India and Australia, has been studied from this stand-point. The current classification of the family has been recently strongly criticized by Hutchinson (1934). He has proposed many changes. To test the phylogenetic value of the different systems it is necessary to have a detailed knowledge of comparative anatomy, embryology and cytology of the different tribes.

Iphigenia indica Kunth, the subject of this investigation, is a small perennial herb. The flexuous stems coming out from globose underground corms bear a few long narrow leaves and purplish flowers with linear-subulate tepals, from which the species can be easily distinguished in its natural environment. The material was collected by the writer from Krusadai Island (S. India) during the month of December 1936. Plants of this species grow there in great abundance in the neighbourhood of the Biological Station. Flowers were picked up at about 10 A.M. and immediately fixed in Navashin's fluid. From this fixative after 24 hours they were directly transferred to 70% alcohol. The material was finally embedded in paraffin according to the customary methods. Sections were cut 8–12 μ thick and stained with Heidenhain's Iron-alum Haematoxylin alone or in combination with Light Green.

Previous Work.

The embryological literature on the Liliaceæ up to the year 1930 has been reviewed by Schnarf (1931). It is therefore unnecessary to summarize it here. The following are the important publications which have appeared since 1931 on the embryo-sac of the Liliaceæ.

Messeri (1931) studied the embryology of six species of *Allium*, *Nothoscordum fragrans* and *N. striatum*. The development of the embryo-sac in the last corresponds to the *Normal*-type. In the other it was found to agree with the *Scilla*-type. An unusual behaviour was observed in *Allium neapolitanum*.

No antipodals were formed and all the four chalazal nuclei of the 8-nucleate embryo-sac were seen to function as polar nuclei. In *A. nigrum*, *A. subhirsutum* and *A. Schoenoprasum* antipodal cells functioning as eggs were observed. Modilewski (1931) described the development of embryo in *Allium odorum*.

Bambacioni (1931) continuing her researches on the development of the embryo-sac of the Liliaceæ showed that the development in *Tulipa praecox* and *Lilium bulbiferum* also corresponds to the *Fritillaria*-type.

Stenar (1932) again investigated the life-history of *Nothoscordum fragrans* and *N. striatum*. The results of his study of embryo-sac development agree with those of Messeri (1931). He further observed the development of the endosperm to follow the *Helobiales*-type, the first instance of this kind noticed in the Allioideæ. Nucellar polyembryony (as the result of adventitious development of embryos from the nucellus) was observed in *N. fragrans*. In 1933, Stenar gave an account of the development of the embryo-sac of *Agapanthus umbellatus* and *Tulbaghia violacea*. In the first species it is of the *Normal*-type, in the second of the *Scilla*-type. Polyembryony was observed in the second. The same author (Stenar, 1934) has also investigated the development of the embryo-sac in *Majanthemum bifolium* and *Smilacina stellata*. In the former plant he has shown definitely that it is of the *Peperomia*-type and corresponds to what Maheshwari (1937) in his recent review of the types of embryo-sacs (of angiosperms) calls the *Drusa*-form. After the completion of the meiotic divisions in the megaspore mother cell three nuclei pass to the chalazal end and one remains at the micropylar end. The following two divisions lead to the formation of four nuclei at the micropylar and twelve at the chalazal end of the embryo-sac. Of the four micropylar nuclei three give rise to the egg-apparatus and one differentiates as the upper polar. Of the twelve chalazal nuclei one moves up as the lower polar, while the remaining eleven form antipodal cells. The development of the embryo-sac of *Smilacina stellata* was traced only up to the 8-nucleate stage. It was found so far to agree exactly with *Majanthemum bifolium*. The 4-nucleate embryo-sac showed the 1+3 arrangement of the nuclei and the 8-nucleate 2+6 arrangement. Stenar, therefore, thinks that in this species also the embryo-sac is of the *Peperomia*-type.

Hoare (1934) studied the development of gametophytes and fertilization in *Scilla nonscripta*. He found the embryo-sac development to follow the *Scilla*-type, but the micropylar dyad cell functions instead of the chalazal. The nucleus of the chalazal cell also divides and forms a 4-nucleate antigone. Maheshwari (1934) in the same year published an account of the male and female gametophytes of *Ophiopogon wallichianus* and Hrubý (1934) investigated the cytology and embryology of *Erythronium dens canis*. The latter found the megaspore mother cell directly developing into the embryo-sac. The 4-nucleate embryo-sac showed 1+3 arrangement of the nuclei. The mature embryo-sac was found to be 8-nucleate. The intervening stages were not seen, but the author supposed that the micropylar nucleus divided twice to

form the egg-apparatus and the upper polar nucleus, while at the chalazal end only one nucleus divided. Maheshwari (1937) has remarked that the author was mistaken in his explanation, but in a recent note Hrubý (1938) confirms his previous findings.

Cooper (1934 and 1935) has studied the development of the embryo-sac in many species of *Lilium* and has shown that in every case it follows the *Fritillaria*-type. Romanov (1936) reports the same type of embryo-sac development in *Gagea ova* and *G. graminifolia* and considers its occurrence very probable in *G. tenera*, which was however not so fully investigated. By comparing Stenar's figures of *Gagea lutea* (Stenar, 1927) with his own observations he concludes that the same type also occurs in this species. Westergård (1936) has also reported the occurrence of *Fritillaria*-type of embryo-sac in *Gagea minima*. Kirch (1936) has made some observations on the embryo-sac of *Lilium longiflorum* and drawn attention to some abnormalities in its development.

Vigodsky de Phillippis (1936) has studied the embryology of *Ruscus aculeatus*. He finds that this species is subdioecious. Some flowers are definitely carpellate. Others in the bud show both carpels and stamens, but the former degenerate, thus leaving the flower staminate. A few flowers reach maturity with both stamens and carpels. Development of the embryo-sac in the true carpellate flowers follows the *Scilla*-type, in flowers with stamens it is of the *Normal*-type.

Wunderlich (1937) has studied the embryology of Scilloideæ investigating chiefly *Muscari racemosum* and *comosum*. Her studies support the views of Schnarf (1929) about the separation of the Scilloideæ from the Lilioideæ, with the former as the more primitive group. Its characteristic *Normal*-type embryo-sac, formation of endosperm as in Helobiales, embryo as long as the seed, small slender generative cell, spherical male nuclei, chromosome numbers of 9, 18 or 27 and presence of raphides are contrasted with the Lilioideæ features, embryo-sac development usually of the *Fritillaria*-type, nuclear endosperm, small embryo, large broadly spindle-shaped generative cell, elongated male nuclei, consistent number of twelve chromosomes and the absence of raphides.

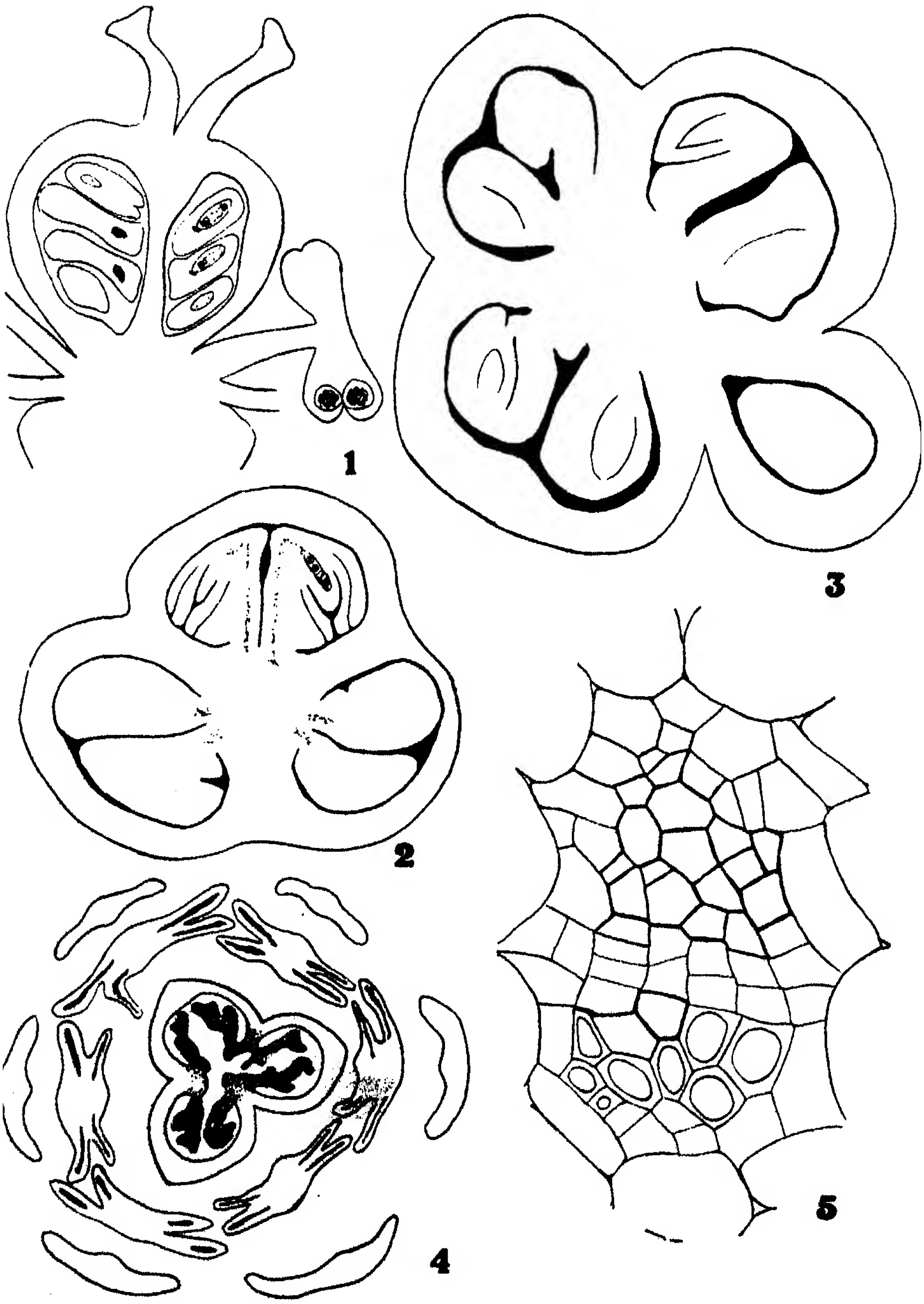
Oikawa (1937) has followed the development of the embryo-sac of *Cardiocrinum cordatum* and shown that it follows the *Fritillaria*-type. The writer (Joshi, 1937) has shown that the embryo-sac of *Aloe vera* is of the *Normal*-type, and the previous observations of Gioelli (1930) on this genus are incorrect. Capoor (1937) has studied the development of male and female gametophytes of *Urginea indica*. Both of these are quite normal. Watkins (1937) has investigated the development of the embryo-sac of *Yucca rupicola*. It is of the *Normal*-type. The mature embryo-sac has a tubular chalazal portion in which are contained the antipodal cells. Wunderlich (1938) has described the ovule, embryo-sac and endosperm of *Yucca filamentosa*. The embryo-sac is of the *Normal*-type and provided with a strongly developed

hypostatis in connection with a well developed vascular system. Development of the endosperm agrees with the *Helobiales*-type, the first instance confirmed among the Dracaenoideæ. Romanov (1938) has studied the development of the embryo-sac of *Tulipa tetraphylla* and *T. ostrovskiana*. He finds that it shows a modification of the *Adoxa*-type, and thus his observations disagree with those of Bambacioni and Giombini (1930) and Bambacioni (1931) on *Tulipa Gesneriana* and *T. praecox* respectively.

Still more recently, Schnarf and Wunderlich (1939) have made a comprehensive study of the embryology of the tribe Asphodeloideæ, investigating the genera *Aloe*, *Gasteria*, *Kniphofia*, *Chlorophytum*, *Echeandia*, *Arthropodium*, *Bowica*, *Dianella*, *Hosta* and *Lomandra*. They find that an aril is present in the first three genera, but absent in others. A primary wall cell is cut off in all except *Dianella*. The development of the embryo-sac follows in very case the *Normal*-type. The development of the endosperm follows according to the *Helobiales*-type in *Chlorophytum*, *Arthropodium*, *Dianella*, *Hosta*, *Kniphofia* and *Gasteria*. In other genera it could not be worked out. Embryo-sac haustoria are found in *Chlorophytum*, *Arthropodium* and *Echeandia*. Multiple embryo-sacs occur in *Dianella tasmanica*. In *Lomandra* the synergids are exceptionally large. The authors in the end discuss the results of their findings on the classification of the tribe. They conclude that the *Aloe*- and *Asphodeline*-groups resemble each other in many characters, viz., bitegmic, krassi-nucellate, arillate ovules, formation of a primary wall cell, *Normal*-type of embryo-sac, *Helobiales*-type of endosperm, simultaneous division of the pollen-mother cells, position of the generative cell precisely opposite to the furrow and haploid chromosome number 7, and should be brought together in one tribe. The *Anthericum*-group differs from the *Aloe*- and *Asphodeline*-groups in the division of the pollen-mother cells in a successive manner, absence of aril in the ovules, development of embryo-sac haustoria and the chromosome numbers 8 and 16, and should be placed in a separate tribe.

Structure of the Gynoecium and the Ovule.

The structure and organization of the flower and the gynoecium is shown in Figs. 1 and 2. The gynoecium is tricarpellary and the ovary trilocular. The placentation is axile and there are two rows of anatropous ovules in each loculus (Fig. 2). Each row consists of three to four ovules (Fig. 1). In an exceptional case the gynoecium was found to be tetracarpellary and the ovary tetralocular (Fig. 3). The extra carpel however was not so well developed as the rest. It had only one row of ovules. In another exceptional flower both the pollen grains and the ovules were found to be abortive. The septa had not fully developed in the ovary in this case, which was consequently unilocular and the placentation parietal (Fig. 4). The abortive ovules had an irregular form.



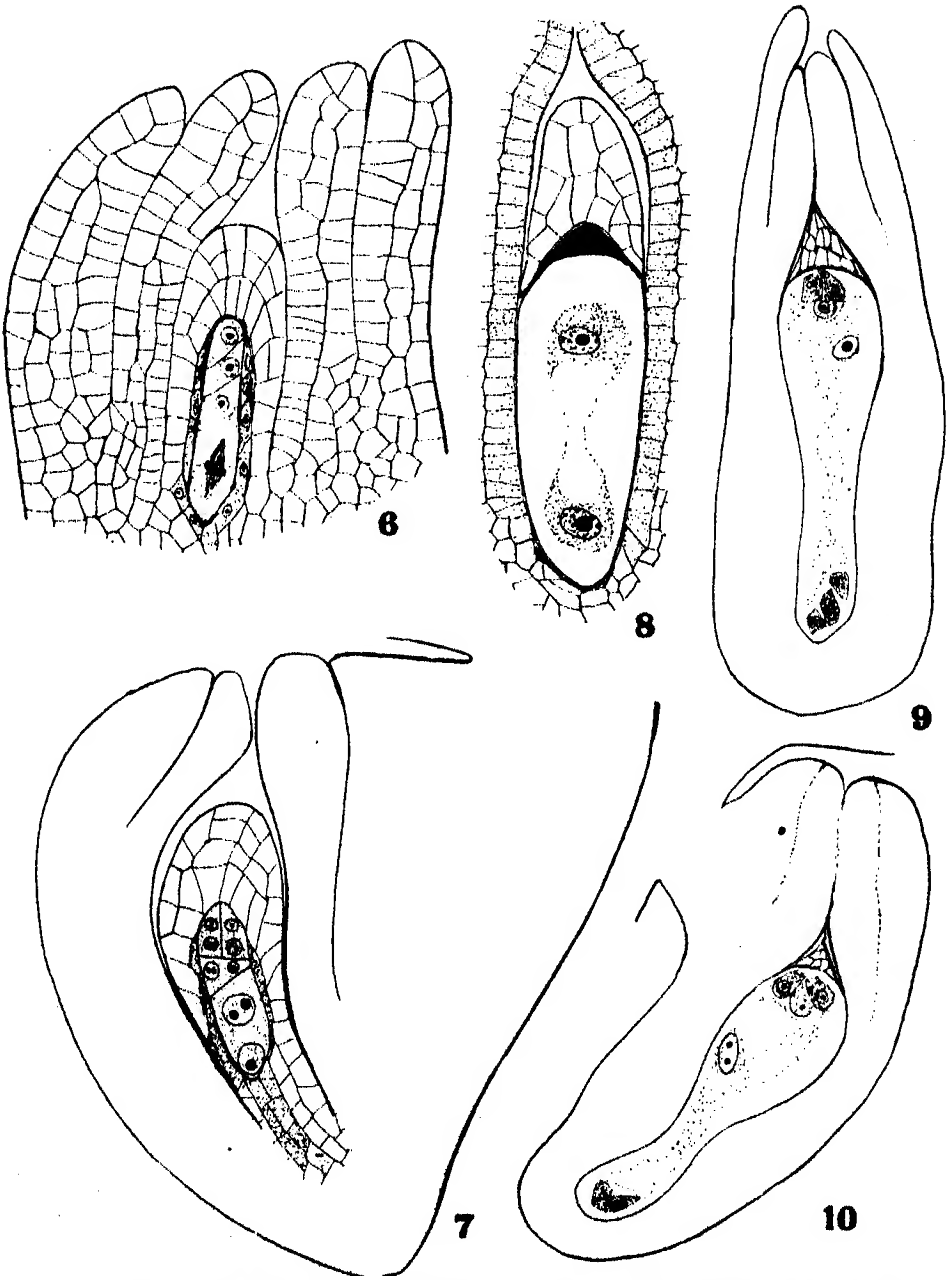
FIGS. 1–5. *Iphigenia indica.* Fig. 1, longitudinal section of a flower showing the arrangement of various parts. Fig. 2, transverse section of the ovary showing the form and arrangement of the ovules. The ovules are at the tetrad stage with 2-nucleate megaspores. Fig. 3, transverse section of an exceptional tetracarpellary tetralocular ovary. Fig. 4, transverse section of a flower with abortive anthers and ovules. Note the parietal placentation. Fig. 5, a vascular bundle from the pedicel showing secondary thickening by an intrafascicular cambium. Fig. 1, × 30; Figs. 2–4, × 165; Fig. 5, × 1050.

A feature of floral organization, which may be mentioned here, is the occurrence of a distinct intrafascicular cambium in the pedicel. Similar intrafascicular cambium is also present in the vascular bundles of the bracts, young leaves and the nodal regions of the young stems. The cambium differentiates along with the primary xylem and phloem, as in a dicotyledonous bundle, and functions in the same manner, forming secondary xylem to the inside and secondary phloem to the outside (Fig. 5), but the amount of the two tissues varies somewhat in different bundles. In some cases the intrafascicular cambium gives rise to almost equal amounts of secondary xylem and secondary phloem, as is the case in Fig. 5, but in other bundles it forms more of secondary xylem or phloem. The occurrence of intrafascicular cambium in the Liliaceæ is already known in many members of the family (Joshi, 1939, and the literature cited there), but there is no previous record of its occurrence in the genus *Iphigenia*.

The structure of the ovule is shown in Figs. 6–10. There are two integuments. The outer is mostly three to five cells thick, the inner two to three cells. The micropyle is formed by the inner integument. The nucellus is poorly developed. At the tetrad stage it consists of two to three layers of cells surrounding the tetrad of megaspores (Fig. 6), but during the development of the 2-nucleate embryo-sac it is mostly absorbed except at the micropylar end (Fig. 8). The embryo-sac from this stage onwards directly touches the inner integument. The conical remnant of the nucellus above the micropylar end of the embryo-sac, however, persists up to the mature embryo-sac stage (Figs. 9 and 10), and even afterwards. I have seen this to be present during the development of the embryo and it is very likely that it persists even in the mature seed. Another feature characteristic of the nucellus is the development of an epidermal cap. As the megaspore mother cell differentiates the cells of the nucellar epidermis at the micropylar end undergo periclinal divisions (Figs. 6, 13 and 22). The cells towards the outside formed as a result of this division in the central region of the nucellus undergo one more division. In this manner an epidermal cap three cells thick in the center and two cells thick at the sides is formed (Fig. 7).

A tapetum differentiates during the development of the embryo-sac. It first arises from the cells of the nucellus surrounding the megaspore mother cell (Fig. 13). Many of these cells are derived from non-functional archesporial cells. They are distinguished from other nucellar cells by their densely staining contents. As the nucellus is disorganized by the growing embryo-sac the cells of the inner epidermis of the inner integument begin to have denser contents and stain deeply. They now assume the function of the tapetum (Fig. 8).

A hypostase-like strand of cells differentiates in the chalazal part of the nucellus as in *Yucca filamentosa* (Wunderlich, 1938). These cells are regularly arranged and have dense cytoplasm, but their walls are not lignified (Fig. 7). They connect the chalazal end of the embryo-sac in the early stages of ovule



FIGS. 6–10. *Iphigenia indica.* Portions or complete longitudinal sections of ovules showing their form and structure of the nucellus and integuments at various stages of development. Fig. 6, at the young tetrad stage. Fig. 7, when the megaspores have become 2-nucleate. Fig. 8, at the 2-nucleate embryo-sac stage. Figs. 9-10, at the mature embryo-sac stage; Fig. 9, section at right angles to the raphe; Fig. 10, section along the raphe. Figs. 6–8, × 330; Figs. 9-10, × 45.

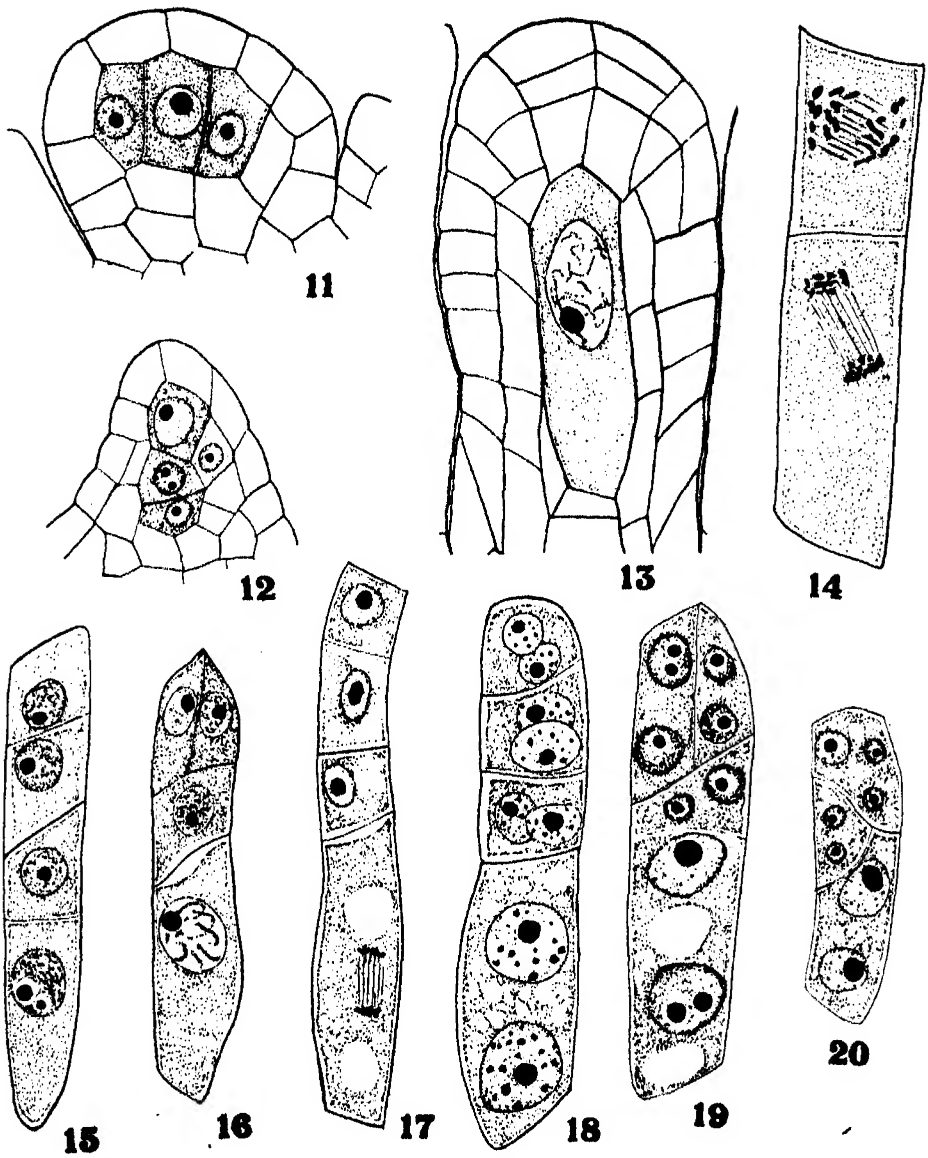
development with the vascular bundle of the ovule ending in the chalaza and probably help in the conduction of the food material from the vascular bundle to the embryo-sac. In the later stages this strand of conducting cells is destroyed by the growing embryo-sac. I have seen a similar strand of cells in the chalazal region of the ovule also in *Gloriosa superba* Linn. and *Gagea fascicularis* Salisb. It appears to be of common occurrence in the family.

Development of the Embryo-sac.

The papilla-like initials of the ovules differentiate from the margins of the carpels before the latter have met in the centre. The archesporium differentiates as the carpellary margins meet one another. The inner integument has appeared by this time above and below but not on the sides of the nucellus. This is clear from the fact that its initials are visible in longitudinal sections of the ovary (Fig. 11) but not in transverse sections (Fig. 12). The archesporium is many-celled and consists of both hypodermal and sub-hypodermal cells (Figs. 11 and 12), though only one cell develops further. The cells surrounding the functional archesporial cell take part in the formation of the tapetum which surrounds the megaspore mother cell (Fig. 13) and the tetrad of megaspores (Figs. 6 and 7). The cells just below the functional archesporial cell, which are often called supporting cells, by repeated divisions form the strand of conducting cells which connects the young embryo-sac with the vascular supply of the ovule.

The functional archesporial cell invariably cuts off a parietal cell, but this or its daughter cells never divide periclinally so that only one layer of parietal cells is formed (Figs. 7, 13 and 22). In the family Liliaceæ as a whole the formation of the parietal cell is very variable. The data in this connection have been reviewed by Dahlgren (1927), so that it is not necessary to repeat them here. Interesting, however, is the fact that in many cases even in the same species, as in *Polygonatum commutatum*, *Medeola virginiaca*, *Smilacina amplexicaulis* (McAllister, 1914), *Ophiopogon wallichianus* (Maheshwari, 1934), etc., a parietal cell may or may not be formed.

The megaspore mother cell generally undergoes the two meiotic divisions in the normal manner (Figs. 13 and 14) and gives rise to a tetrad of megaspores. The only variable feature is that the spindle in the micropylar dyad cell during the second meiotic division may be orientated either lengthwise or transversely. The tetrad of megaspores therefore may be linear (Figs. 15, 17 and 18) or T-shaped (Figs. 16 and 19). Both types of tetrads are met with in almost equal proportion. The interesting thing about the further development of the tetrad is that all the megaspores become 2-nucleate (Figs. 18 and 19), although only the chalazal megaspore which is larger than the rest from the very beginning develops into the embryo-sac. The division of the nucleus commences in the chalazal megaspore (Figs. 16 and 17) which becomes 2-nucleate. Later the nuclei of other megaspores also divide. Vacuolation takes



FIGS. 11–20. *Iphigenia indica.* Early stages in the development of the embryo-sac. Figs. 11-12, primary archesporium. Fig. 13, a nucellus with the megaspore mother cell in the prophase of the first meiotic division. Fig. 14, a megaspore mother cell showing the telophase of the second meiotic division. Fig. 15, a linear tetrad of megaspores. Fig. 16, a T-shaped tetrad with the nucleus of the chalazal megaspore in prophase. Fig. 17, a linear tetrad with the nucleus of the chalazal megaspore in telophase. Figs. 18 and 19, linear and T-shaped tetrads; all the megaspores have reached the 2-nucleate stage. Fig. 20, an abnormal tetrad; no wall has appeared after the second meiotic division in the micropylar dyad cell. Fig. 14, × 1050; the rest, × 720.

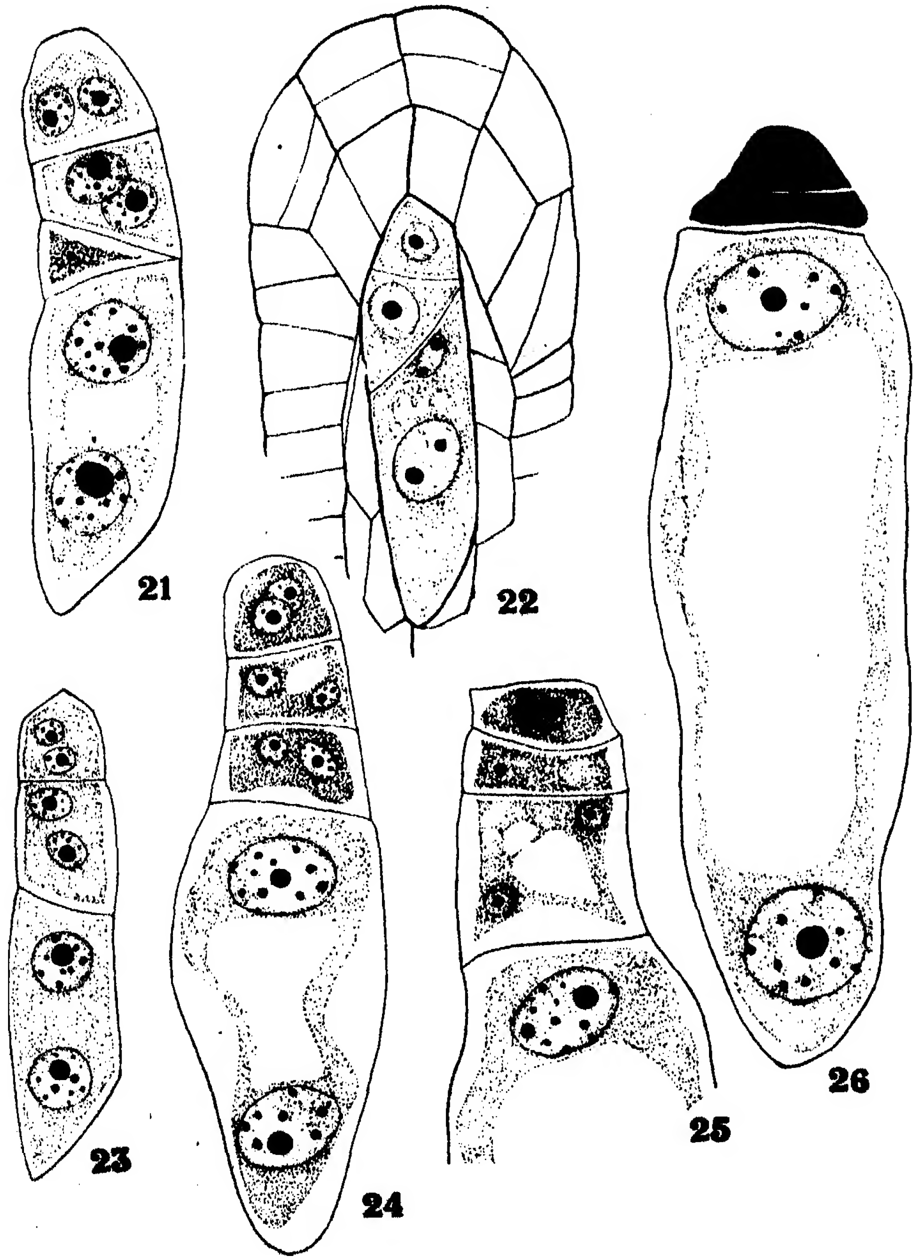
place in the usual manner in the chalazal megaspore (Figs. 17–19). The other megaspores generally remain non-vacuolate even after becoming 2-nucleate, but occasionally in the later stages they may develop a vacuole between the two nuclei (Figs. 24 and 25) and thus resemble typical 2-nucleate embryo-sacs. The three micropylar megaspores always degenerate ultimately, while the chalazal megaspore develops into the 8-nucleate embryo-sac in the normal manner. The 2-nucleate stage is of very long duration in the development of the embryo-sac. It was most commonly met with in the preparations that I examined, and the embryo-sac during this stage undergoes great increase in size, as is clear from the comparison of Figs. 17 and 26. The 4- and 8-free-nucleate stages of the embryo-sac are passed through quickly.

While in most cases the development of the embryo-sac follows the method described above, a few exceptional cases were also observed. Fig. 20 shows one of these. Here the megaspore mother cell has given rise to only three cells. The lowest is the chalazal megaspore, now 2-nucleate, which would have developed into an 8-nucleate embryo-sac. The next cell is its sister megaspore which has also reached the 2-nucleate condition. Finally there is a cell at the upper end which is 3-nucleate. One of the nuclei is larger than the other two and between the large nucleus and the two smaller nuclei small vacuoles have appeared. The cell is obviously the result of the suppression of wall formation after the second meiotic division in the micropylar dyad cell. It can be regarded as a small 3-nucleate embryo-sac developing according to the *Scilla*-type in which the division after the 2-nucleate stage has not taken place simultaneously in both the nuclei.

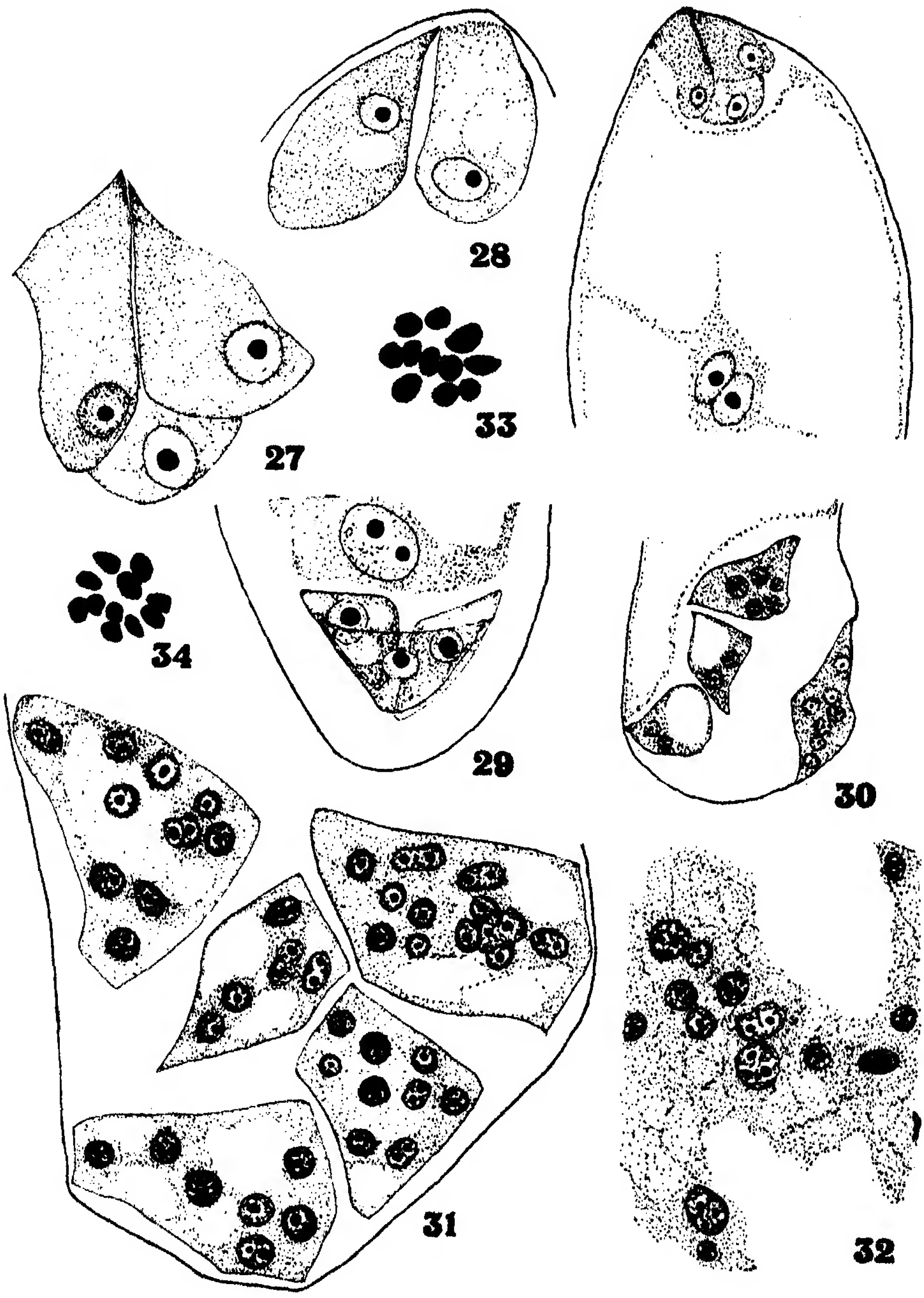
Other exceptional cases are sketched in Figs. 21–23. The tetrad sketched in Fig. 21 shows only a small departure from the normal behaviour in that the megaspore sister to the chalazal one has degenerated early. In Fig. 22 no wall has appeared in the chalazal dyad cell after the second meiotic division. Also the nucleus formed towards the micropylar side is small and likely to degenerate during further development. The embryo-sac in this case would have developed from the cytoplasm of two but nucleus of one megaspore. It would thus be intermediate between the *Normal*- and the *Scilla*-types. Lastly three cases were seen by me in which it appears that no wall had appeared in the chalazal dyad cell after the second meiotic division and the nuclei formed as a result of this had been equal in size, so that the chalazal dyad cell had directly given rise to a 2-nucleate embryo-sac (Fig. 23). These embryo-sacs differed from other 2-nucleate embryo-sacs of the same size in the absence of any signs of vacuolation and it seems certain that the 8-nucleate embryo-sac in these cases would have developed according to the *Scilla*-type.

The Mature Embryo-sac.

The mature embryo-sac is a large cylindrical structure with a pouch-like extension at the chalazal end containing the antipodals (Figs. 9 and 10).



FIGS. 21–26. *Iphigenia indica*. Figs. 21–23, three cases of abnormal megasporogenesis. For further explanation see text. Fig. 24, an old tetrad. Fig. 25, micropylar megaspores about the time of degeneration. Fig. 26, a fully developed 2-nucleate embryosac. × 720.



FIGS. 27–34. *Iphigenia indica*. Fig. 27, a normal egg-apparatus. Fig. 28, an egg and a synergid. Fig. 29, young 1-nucleate antipodals. Fig. 30, the chalazal and micropylar portions of an embryo-sac showing the antipodals, fusion of polar nuclei and the egg-apparatus. Fig. 31, old antipodals. Fig. 32, antipodals as they degenerate. Figs. 33-34, chromosomes from the first meiotic division in the pollen-mother cells; Fig. 33, polar view of metaphase; Fig. 34, polar view of early telophase. Figs. 27–29 and 31-32, × 720; Fig. 30, × 330; Figs. 33-34, × 1500.

The egg has the usual structure (Figs. 27 and 28), but the synergids are of an unusual type. Occasionally they may show a small vacuole (Fig. 28). Usually they lack any vacuolation and are completely full of dense cytoplasm (Fig. 27). Their nucleus is usually near the chalazal end as in the egg. Watkins (1937) has also noted that the synergids in *Yucca rupicola* are densely filled with cytoplasm. The polar nuclei meet and fuse in the micropylar half of the embryo-sac (Figs. 9, 10 and 30). The three antipodals are at first small and uni-nucleate (Fig. 29), but soon their nuclei begin to divide and they become multi-nucleate (Figs. 30 and 31). Their number may also increase to four or five. I have counted up to about twenty-five nuclei in one antipodal cell. In the later stages many of these nuclei fuse in groups of 2–7. The antipodal cells also develop prominent vacuoles. Very frequently they persist even after fertilization. I have seen them in embryo-sacs with about a hundred endosperm nuclei. The oospore in these cases was however still undivided. As the antipodals degenerate they form a plasmodial mass in which many nuclei float freely (Fig. 32). Antipodals of the same type in the family Liliaceæ are present in the genera *Veratrum* and *Zygadenus* (Stenar, 1928).

Chromosomes.

The upper (micropylar) dyad cell in Fig. 14 shows clearly 11 chromosomes on the left hand side of the homotypic spindle. The same haploid number has been counted from the polar views of metaphase (Fig. 33) and early telophase (Fig. 34) of the I meiotic division in pollen-mother cells.

Discussion.

The most notable feature in the life-history of *Iphigenia indica* is the variation in the development of the embryo-sac. Usually the development follows the *Normal*-type, but occasionally it takes place according to the *Scilla*-type. Similar variation in the development of the embryo-sac in the Liliaceæ was observed by Schniewind-Thies (1901) in *Galtonia candicans*, and recently Vigodsky de Phillippis (1936) has found that in *Ruscus aculeatus* the development follows according to the *Normal*-type in hermaphrodite flowers and according to the *Scilla*-type in the true carpellate flowers. The following are examples from other families in which the embryo-sac develops generally according to the *Normal*-type but sometimes according to the *Scilla*-type:

Oxybaphus nyctagineus ***Mirabilis Jalapa***	Nyctaginaceæ	Rocén (1927)
Ionopsidium acaule	Cruciferæ	Corti (1930)
Dionaea muscipula	Droseraceæ	Smith (1929)
Xanthoxylum alatum ***X. Bungei***	Rutaceæ	Mauritzon (1935)
Myrtus communis	Myrtaceæ	Greco (1930)

Syringa vulgaris	Oleaceæ	Andersson (1931)
Rhytidophyllum crenulatum	Gesneriaceæ	Cook (1907)
Hypoxis decumbens	Amaryllidaceæ	Stenar (1925)
Epipactis latifolia	Orchidaceæ	Vermoesen (1911)
Epipactis pubescens	Orchidaceæ	Brown & Sharp (1911)
Gyrostachys cernua } *Gyrostachys gracilis* }	Orchidaceæ	Pace (1914)
Orchis sambucina	Orchidaceæ	Afzelius (1916)

It is to be seen from the above that most commonly this type of variation has been observed in the family Orchidaceæ. The development in *Iphigenia indica*, however, is interesting in that it has been possible to demonstrate intermediate stages between the two types.

The second feature worth noting in *Iphigenia indica* is that even the non-functional megaspores always develop up to the 2-nucleate stage. Exactly similar behaviour of the megaspores has been observed by Afzelius (1918) in species of *Gloriosa*, and *Uvularia*, which is closely related to *Gloriosa*, is another genus showing the same character (Schnarf, 1931). The development of generally non-functional megaspores into 2-, 4- or 8-nucleate embryo-sacs as an abnormality, however, is known among many Liliaceæ, e.g., *Galtonia candicans* and *Convallaria majalis* (Schniewind-Thies, 1901), *Velthemia viridifolia* (Stiffler, 1925), etc. In many species, in which the development of the embryo-sac follows the *Scilla*-type, it frequently happens, when the micropylar dyad cell develops into the complete embryo-sac, the chalazal develops up to the 4-nucleate stage. This is the case in *Agraphis* (*Scilla*) *patula* (Treub and Mellink, 1880), *Agraphis nutans* and *A. campanulata* (Guignard, 1882), *Scilla hyacinthoides* v. *cærulea* (McKenny, 1904), *Scilla sibirica* (Schniewind-Thies, 1901), *Scilla nonscripta* (Hoare, 1934), etc. Examples from other families of monocotyledons and dicotyledons in which the generally non-functional megaspores undergo further development have been reviewed by Palm (1915) and Afzelius (1918).

Other interesting features of the embryo-sac of *Iphigenia indica* are the absence of the usual vacuoles in the synergids and the multi-nucleate nature of the antipodals.

As regards the affinities of the Iphigenieæ it is not possible to say much just at present on embryological grounds, because so far only one member of the tribe has been investigated. So far as this knowledge goes, it points towards a relationship with the tribe Uvularieæ of Hutchinson (1934), which includes the genera *Schelhammera, Uvularia, Kreysigia, Littonia, Sandersonia, Walleria* and *Gloriosa*. These genera with the exception of *Uvularia*, which is North American, have the same distribution as the genera of Iphigenieæ, being distributed over Africa, Tropical Asia and Australia. Out of these the development of the embryo-sac has been investigated so far only in the genera *Uvularia* and *Gloriosa*. With these *Iphigenia* resembles not only in

the behaviour of the non-functional megaspores which has been emphasized above but also in the structure of the nucellus. My observations (unpublished) on *Gloriosa superba* Linn. show that there is a differentiation of the tapetum and epidermal cap formation at the micropylar end of the nucellus of the same type as in *Iphigenia indica*. The mature embryo-sac destroys the entire nucellus except the cap at the micropylar end. Similar behaviour of the nucellus has been figured by Afzelius (1918, p. 7, fig. 8b) in *Gloriosa virescens* In showing resemblance with the genera *Zygadenus* and *Veratrum* in the structure of the antipodals, the genus *Iphigenia* also shows some affinity with the tribe Veratreæ.

SUMMARY.

The development of the embryo-sac of *Iphigenia indica* follows the *Normal*-type, occasionally the *Scilla*-type. An intermediate stage between the two types is also described. The tetrad of megaspores is linear or T-shaped. The chalazal megaspore develops into the embryo-sac, but the non-functional megaspores also always develop up to the 2-nucleate stage. The mature embryo-sac has synergids without vacuoles and multi-nucleate antipodals.

The ovules are anatropous and bitegmic. The inner integument forms the micropyle. The nucellus is poorly developed and possesses an epidermal cap. It is mostly absorbed by the growing embryo-sac except the small cap at the micropylar end. The functional archesporial cell cuts off a parietal cell.

The tribe Iphigenieæ appears on embryological evidence to be related to the Uvularieæ. It also shows some affinity with the Veratreæ.

LITERATURE CITED.

Afzelius, K. 1916. Zur Embryosackentwicklung der Orchideen. *Svensk Bot. Tidskr.*, 10: 183–227.

———. 1918. Zur Entwicklungsgeschichte der Gattung *Gloriosa*. *Acta Horti Bergiani*, Band 6, No. 3.

Andersson, A. 1931. Studien über die Embryologie der Familien Celastraceæ, Oleaceæ und Apocynaceæ. *Acta Univ. Lund*, Avd. 2, 27: 1–112.

Bambacioni, V. 1931. Nuove ricerche sull' embriologia delle Gigliacee. *Ann. Bot., Roma*, 19: 365–382.

Bambacioni, V. and Giombini, A. 1930. Sullo sviluppo del gametofito femminile in *Tulipa gesneriana L. Ann. Bot., Roma*, 18: 373–386.

Capoor, S. P. 1937. Contribution to the morphology of some Indian Liliaceæ. II. The gametophytes of *Urginea indica* Kunth. *Beih. Bot. Zbl.*, 56: 156–170.

Cook, M. T. 1907. The embryology of *Rhytidophyllum*. *Bull. Torr. Bot. Club*, 34: 179–184.

Cooper, D. C. 1934. Development of the embryo sac of *Lilium Henryi*. *Proc. Nat. Acad. Sci.*, 20: 163–166.

———. 1935. Macrosporogenesis and development of the embryo sac of *Lilium Henryi*. *Bot. Gaz.*, 97: 346–355.

Corti, R. 1930. Embriologia del genere *Ionopsidium* Rchb. *Nuovo giorn. bot. Ital.*, 37: 510–526.

Dahlgren, K. V. O. 1927. Die Morphologie des Nuzellus mit besonderer Berücksichtigung der deckzellosen Typen. *Jahrb. f. wiss. Bot.*, 67: 347–426.

Gioelli, F. 1930. Ricerche sullo sviluppo del gametofito femmineo e del polline nel genere *Aloe*. *Lavori istit. bot. Palermo*, 1: 61–84.

Greco, R. 1930. Embriologia del *Myrtus communis*. *Nuovo giorn. bot. Ital.*, 37: 609–630.

Guignard, L. 1882. Recherches sur le sac embryonnaire des phanérogames angiospermes. *Ann. Sci. Nat., Bot.*, Sér. 6, 13: 136–199.

Hoare, G. V. 1934. Gametogenesis and fertilization in *Scilla non-scripta*. *La Cellule*, 42: 269–291.

Hrubý, K. 1934. A contribution to the cytology and embryology of *Erythronium dens canis* L. *Bull. Internat. Acad. Sci. Bohême*, pp. 1–9.

————. 1938. Embryo sac development in *Erythronium dens canis*. *Chron. Bot.*, 4: 20-21.

Hutchinson, J. 1934. The families of flowering plants. Vol. II. London.

Joshi, A. C. 1937. Megasporogenesis in *Aloe vera* Linn. *Jour. Ind. Bot. Soc.*, 16: 297–300.

————. 1939. Intrafascicular cambium in a monocotyledon. *Curr. Sci.*, 8 (1): 16.

Kirch, M. H. 1936. Some abnormalities in the development of the embryo-sac of *Lilium logiflorum*. *Bull. Torr. Bot. Club*, 63: 383–388.

Maheshwari, P. 1934. Contribution to the morphology of some Indian Liliaceæ. I. The gametophytes of *Ophiopogon wallichianus* Hook. f. *Proc. Ind. Acad. Sci.*, B, 1: 197–204.

————. 1937. A critical review of the types of embryo sacs in angiosperms. *New Phytol.*, 36: 359–417.

Mauritzon, J. 1935. Über die Embryologie der Familie der Rutaceæ. *Svensk Bot. Tidskr.*, 29: 319–347.

McAllister, F. 1914. The development of the embryo sac in the Convallariaceæ. *Bot. Gaz.*, 58: 137–153.

McKenney, R. E. B. 1904. Observations on the development of some embryo sacs. *Contr. Bot. Lab. Univ. Pennsylvania*, 2: 80–86.

Messeri, A. 1931. Recerche embriologiche e cariologiche spora i genori *Allium* e *Nothoscordum*. *Nuovo giorn. bot. Ital.*, 38: 409–441.

Modilewski J. 1931. Die Embryobildung bei *Allium odorum* L. *Bull. Jard. Bot. Kieff*, 12-13: 27–48.

Oikawa, K. 1937. A note on the development of the embryo-sac in *Cardiocrinum cordatum*. *Sci. Rep. Tohoku Imp. Univ.*, IV Ser., Biol., 11: 303–306.

Pace, L. 1914. Two species of *Gyrostachys*. *Baylor Univ. Bull.*, 17: 1–16.

Palm, B. 1915. Studien über Konstruktionstypen und Entwicklungswege des Embryosackes der Angiospermen. Diss. Stockholm.

Rócen, Th. 1927. Zur Embryologie der Centrospermen. Diss. Uppsala.

Romanov, I. D. 1936. Die Embryosackentwicklung in der Gattung *Gagea*. *Planta*, 25: 438–459.

————. 1938. Eine neue Form des Embryosackes von *Adoxa*-Typus bei *Tulipa tetraphylla* und *T. ostrovskiana*. *C. R. Acad. Sci. USSR.*, 19: 113–115.

Schnarf, K. 1929. Die Embryologie der Liliaceæ und ihre systematische Bedeutung. *Sitzb. Akad. Wien*, math.-nat., Kl. 138: 69–92.

————. 1931. Vergleichende Embryologie der Angiospermen. Berlin.

Schnarf, K. and Wunderlich, R. 1939. Zur vergleichenden Embryologie der Liliaceae-Asphodeloideae. *Flora*, Neue Folge, 33 : 297–327.

Schniewind-Thies, J. 1901. Die Reduktion der Chromosomenzahl und die folgenden Kernteilung in den Embryosackmutterzellen der Angiospermen. Jena.

Smith, C. M. 1929. Development of *Dionaea muscipula.* I. Flower and seed. *Bot. Gaz.*, 87: 507–530.

Stenar, H. 1925. Embryologische Studien. I. Zur Embryologie einiger Columniferen. II. Die Embryologie der Amaryllidaceen. *Akad. Abh. Uppsala.*

————. 1927. Über die Entwicklung des siebenkernigen Embryosackes bei *Gagea lutea* Ker. nebst einigen Bemerkungen über die Reduktionsteilung bei *Gagea minima* Ker. *Svensk Bot. Tidskr.*, 21: 344–360.

————. 1928. Zur Embryologie der *Veratrum-* und *Anthericum*-Gruppe. *Bot. Not.*, 357–378.

————. 1932. Studien über die Entwicklungsgeschichte von *Nothoscordum fragrans* und *N. striatum. Svensk Bot. Tidskr.*, 26 : 25–44.

————. 1933. Zur Embryologie der *Agapanthus*-Gruppe. *Bot. Not.*, 520–530.

————. 1934. Embryologische und zytologische Beobachtungen über *Majanthemum bifolium* und *Smilacina stellata. Ark. Bot.*, 26: 1–20.

Stiffler, E. G. 1925. Development of embryo sac in *Gasteria, Cyrtanthus* and *Velthemia. Bot. Gaz.*, 79: 207–216.

Treub, M. and Mellink, J. 1880. Notice sur le développement du sac embryonnaire dans quelques Angiospermes. *Arch. Néerl. des Sci.*, 15: 452–457.

Vermoesen, C. 1911. Contribution à l'étude de l'ovule, du sac embryonnaire et de la fécondation dans les Angiospermes. *La Cellule*, 27: 113–162.

Vigodsky de Phillippis, A. 1936. Richerche embriologiche su *Ruscus aculeatus* L. *Nuovo giorn. bot. Ital.*, 43:707–734.

Watkins, G. M. 1937. Embryo-sac development in *Yucca rupicola. Amer. Jour. Bot.*, 24: 481–484.

Westergård, M. 1936. A cytological study of *Gagea spathacea* with a note on the chromosome number and embryo-sac formation in *Gagea minima. C. R. Trav. Lab. Carlsberg*, Sér. Phys., 21 : 437–451.

Wunderlich, R. 1937. Zur vergleichenden Embryologie der Liliaceæ-Scilloideæ. *Flora*, 32: 48–90.

————. 1938. Ein künstlich bestäubter Fruchtknoten von *Yucca filamentosa. Öster-Reich. Bot. Zeitschr.*, 87: 109–113.

Eleventh Ordinary General Meeting.

The Eleventh Ordinary General Meeting of the National Institute of Sciences of India was held at 11–30 A.M. on Wednesday, the 5th April, 1939, in the hall of the Royal Asiatic Society of Bengal, 1, Park Street, Calcutta.

The following Fellows were present:—

Bt.-Col R. N. Chopra, *President*, (in the Chair).
Prof. J. N. Mukherjee, *Additional Vice-President*.
Prof. M. N. Saha, *Additional Vice-President*.
Dr. B. S. Guha, *Honorary Treasurer*.
Prof. S. R. Bose.
Dr. B. N. Chopra.
Prof. S. Datta.
Mr. D. Hendry.
Dr. S. L. Hora.
Dr. R. B. Lal.
Prof. S. K. Mitra.
Prof. P. Neogi.
Dr. H. Srinivasa Rao.
Principal J. M. Sen.
Dr. A. C. Ukil.
Prof. S. P. Agharkar, *Honorary Secretary*.

Besides the Fellows there were also some visitors present.

1. The minutes of the Fourth Annual General Meeting were read and confirmed.

2. Mr. D. Hendry signed the duplicate obligation and was admitted a Fellow under Rule 13.

3. The following papers were read and discussed:—

(1) Reflection and absorption of electro-magnetic waves in the Ionosphere. By K. B. Mathur. (Communicated by Prof. M. N. Saha).

(2) Studies on the Ionosphere at Allahabad. By B. D. Pant and R. R. Bajpai. (Communicated by Prof. M. N. Saha).

(3) Structure and development of the Embryo-sac of *Iphegenia indica*. By A. C. Joshi.

(4) Physiology of respiration and evolution of air-breathing Fishes. By S. L. Hora.

(5) On the burrowing habits of the Gobioid Fish *Tænioides rubicundus* (Ham.) in the Andamans. By H. Srinivasa Rao.

(6) Importance of dialysis in the study of colloids. By B. N. Desai and P. M. Barve. (Communicated by Dr. S. K. Banerji).

With a vote of thanks to the chair the meeting terminated.

THE EXTENSION OF THE (O, O) BAND OF OD.

By M. Ishaq, *M.Sc., Ph.D., D.I.C., Department of Physics, Muslim University, Aligarh.*

(Communicated by Professor M. N. Saha, F.R.S.)

(Received May 26, 1939.)

The tail end of the OD spectrum taken in the 4th order of a 10-foot concave grating described in the *Proceedings of the National Institute of Sciences, Calcutta*, Vol. III, No. 4, pp. 389–409, 1937, was measured and the (O, O) band has been considerably extended.

Measurements were made by comparison with the iron arc. The iron standards were taken from Kayser Handbuch der Spectroskopie, Vol. VII. The dispersion of the grating in the region of the spectrum is about 1·3 A/mm.

The branches Q_1 and Q_2 are extended from K_{25} to K_{37} and K_{24} to K_{37} respectively, P_1 from K_{17} to K_{19} and P_2 from K_{16} to K_{24}. These extensions are given in table I.

Table I.

K	Q_1	Q_2
24		31953·67(3)
25	31937·65(3)	909·33(3)
26	890·54(3)	862·98(2)
27	841·43(3)	814·54(3)
28	790·23(3)	763·99(3)
29	736·97(3)	711·21(3)
30	682·05(3)	656·87(3)
31	624·68(4)	599·80(2)
32	564·89(3)	540·49(3)
33	502·85(2)	478·81(3)
34	438·41(2)	414·92(3)
35	371·64(2)	348·46(3)
36	302·33(1)	279·54(2)
37	230·77(2)	208·60(2)

K	P_1	P_2
16		31957·13(3)
17	31951·74(2)	912·65(2)
18	904·00(2)	866·40(2)

[Published August 24th, 1939.

K	P_1	P_2
19	854·04(3)	818·50(3)
20		768·91(3)
21		717·77(3)
22		665·27(3)
23		610·74(3)
24		554·51(2)

The rotational term differences for the $^2\Sigma$ state are calculated by the method described by the author in the previous paper referred to above. These differences from the extended branches are shown in table II.

TABLE II. ROTATIONAL TERM DIFFERENCES FOR THE $^2\Sigma$ STATE.

K	$R_1(K+1) - P_1(K+1)$	$R_2(K+1) - P_2(K+1)$
15	575·80	575·97
16	608·35	608·19
17	640·37	639·45
18	671·66	669·53
19		698·72
20		726·61
21		753·08
22		778·45
23		802·54

The rotational term differences for the $^2\Pi$ state are calculated by the same method as employed by the author in 1937. These differences are given in tables III and IV.

TABLE III. ROTATIONAL TERM DIFFERENCES FOR THE $^2\Pi_{1\frac{1}{2}}$ STATE.

K	$R_1(K) - Q_1(K+1)$	K	$Q_1(K) - P_1(K+1)$
24	468·43	16	322·76
25	484·77	17	340·33
26	500·86	18	357·54
27	516·60		
28	532·15		
29	546·91		
30	561·42		
31	575·97		

TABLE IV. ROTATIONAL TERM DIFFERENCES FOR THE $^2\Pi_{\frac{1}{2}}$ STATE.

K	$R_2(K)$ — $Q_2(K+1)$	K	$Q_2(K)$ — $P_2(K+1)$
23	435·52	15	305·19
24	447·72	16	323·19
25	459·38	17	340·95
		18	358·50
		19	375·71
		20	392·67
		21	408·97
		22	425·32
		23	441·38

The mean of the Λ-doubling in the levels F(K) and F(K+1) are given in table V.

TABLE V. Λ-DOUBLING.

K	$^2\Pi_{\frac{3}{2}}$ state.	$^2\Pi_{\frac{1}{2}}$ state.
14	−2·85	−0·90
15	−3·35	−1·05
16	−3·50	−1·28
17	−3·64	−1·45
18	−4·01	−1·36
19	....	−0·94
20	....	−0·36
21	....	+0·18
22	....	+1·42
23	....	+2·93

The rotational constants for the upper and lower states are not appreciably effected by these extensions. Their values have been recalculated and are given in table VI.

TABLE VI. ROTATIONAL CONSTANTS FOR THE (0, 0) BANDS OF OD AND OH.

	B'_v	D'_v	B''_v	D''_v
OD ..	9·039	$0{\cdot}580 \times 10^{-3}$	9·870	$0{\cdot}450 \times 10^{-3}$
OH ..	16·955	$2{\cdot}00 \times 10^{-3}$	18·516	$1{\cdot}82 \times 10^{-3}$

Values for the OH band are taken from Tanaka and Koana, *Proc. Physico-Math. Soc. Japan*, 15, 272 (1933).

HEAT OF IONIC DISSOCIATION OF THE CHLORIDE AND BROMIDE OF RUBIDIUM.

By B. N. SRIVASTAVA, *M.Sc., Lecturer in Physics, Allahabad University.*

(Communicated by Prof. M. N. Saha, D.Sc., F.R.S.)

(*Received April 24, 1939.*)

The heat of dissociation of an alkali halide vapour MX into its constituent ions—the positive alkali ion M^+ and the negative halogen ion X^-, may be called the 'heat of ionic dissociation' of the MX molecule. This quantity is of great theoretical importance as a knowledge of it directly enables us to calculate the lattice energy of the crystal and also the electron affinity of the halogen if certain thermochemical data be known. For this reason during recent years various attempts have been made to determine this quantity both theoretically and experimentally.

Among the theoretical attempts the most important work is that of Max Born and J. E. Mayer (1932) who have improved upon the older theory of ionic crystals by taking into account some additional factors and obtained a formula for the lattice energy. This has been utilized by L. Helmholtz and J. E. Mayer (1932) and others for calculating the lattice energies of the alkali halides and some other salts. M. L. Huggins (1937) has recalculated the lattice energies by taking into account more recent data. From these results the heat of ionic dissociation and also the electron affinity can be calculated and this has been done by L. Helmholtz and J. E. Mayer (1932) by utilizing thermochemical data, while J. E. Mayer and I. H. Wintner (1938) have recalculated the values of the heat of ionic dissociation and some other quantities for some halides in the light of more recent data.

On the experimental side the work was started by J. E. Mayer (1930) who investigated the dissociation of the iodides of cæsium and potassium and later, in collaboration with L. Helmholtz (1934), he worked with RbBr and NaCl. Their apparatus was not suitable for very high temperatures and in fact their experiments with RbBr extend only up to 1046°C. In order to carry on the work at much higher temperatures an improved apparatus was constructed by M. N. Saha and A. N. Tandon (1936) which was utilized by them (1937) for studying the dissociation of KCl, NaCl and LiCl, and by A. N. Tandon (1937*a*, 1937*b*) for investigating the dissociation of KBr and NaBr, and KI and NaI. The principle of this method is to lead the alkali halide vapour MX into a chamber maintained at a high temperature and determine the quantity of M^+ and X^- ions formed as a result of thermal dissociation by measuring the respective ion currents obtained by the effusion

of these ions through a narrow orifice. The vapour pressure of the alkali halide is known from the temperature of the subsidiary furnace. We can then determine the equilibrium constant of ionic dissociation from which the heat of ionic dissociation is easily calculated with the help of the usual dissociation formula.

In all the foregoing investigations no attempt was made to distinguish the negative ion current from the electron current. The present author (Srivastava, 1938) improved the apparatus by inserting a pair of electromagnets in such a position that the magnetic field was perpendicular to the effusing ion beam. Thus by applying a suitable magnetic field the electrons were deflected off and the negative ion current alone measured. In this way the heat of dissociation of RbI and LiI was found. In the present paper the same apparatus has been used to study the dissociation of RbCl and RbBr. The lattice energy of these halides and the electron affinity of the halogens have also been calculated.

THEORY.

When the alkali halide vapour MX enters the region of high temperature the following reactions take place:—

$$MX \rightleftarrows M+X-D, \quad \ldots \quad (1)$$

$$MX \rightleftarrows M^{+}+X^{-}-Q, \quad \ldots \quad (2)$$

$$M \rightleftarrows M^{+}+e-I_{M}, \quad \ldots \quad (3)$$

$$X^{-} \rightleftarrows X+e-E_{X}, \quad \ldots \quad (4)$$

$$X_2 \rightleftarrows 2X-D', \quad \ldots \quad (5)$$

where D is the heat of atomic dissociation of the alkali halide, Q the heat of ionic dissociation, I_M the ionization potential of the alkali, M, E_X the electron affinity of the halogen atom and D′ the heat of dissociation of the halogen molecule. In addition to these, some X^+ and M^- ions may also be formed due to the electron affinity of the alkali atom and the ionization of the halogen atom but their amounts will be negligible on account of the very small electron affinity of the alkali atom and the high ionization potential of the halogen atom. (In fact Glockler (1934) by a semi-empirical interpolation found for the electron affinity of Li and Na the values +0·34 and +0·08 volts respectively.) It can be shown from thermodynamic theory that the dissociation constant K_2 of the reaction (2) is given by the formula

$$\log K_2 = \log \frac{p_{M^+}p_{X^-}}{p_{MX}} = -\frac{Q}{2{\cdot}3RT}+\frac{3}{2}\log T+\log\left(1-e^{-h\nu/kT}\right)$$

$$+\log\left[\frac{k^{3/2}}{2^{3/2}\cdot\pi^{1/2}Ih}\left(\frac{m_{M^+}m_{X^-}}{m_{MX}}\right)^{3/2}\right], \quad \ldots \quad (6)$$

where ν is the frequency of linear vibration of the atoms in the molecule of the gaseous halide MX, I the moment of inertia of the molecule and m_{M^+}, m_{X^-}, m_{MX} the masses of the ion or the molecule.

From considerations of Born's cycle we get

$$E_X = D + I_M - Q \quad \ldots \quad (7)$$

and the lattice energy $\phi(r_0)$ is given by

$$\phi(r_0) = Q + L_{XM}, \quad \ldots \quad (8)$$

where L_{MX} is the heat of sublimation of MX at the absolute zero.

Apparatus.

The demountable vacuum graphite furnace employed in these experiments has been described in detail by M. N. Saha and A. N. Tandon (1936). The internal arrangement followed here is slightly different from theirs and has been fully described by the author (Srivastava, 1938). The electromagnet and the auxiliary furnace as described there were employed in this work also. Two sizes of auxiliary furnace were used for giving two sets of readings with differing vapour pressures. Further, it was found more convenient to prepare the auxiliary tube in one piece by boring from one side up to some depth.

The effusion beam is limited by a diaphragm of radius r placed at a distance d from the effusion hole. Behind the diaphragm is a Faraday cylinder connected to a sensitive galvanometer and suitable positive or negative potentials were applied between the Faraday cylinder and the diaphragm in order to collect the ions of the desired charge. Under these conditions it can be shown (see Srivastava, *loc. cit.*) that the galvanometer current i is given by the relation

$$i = \frac{epS}{\sqrt{2m\pi kT}} \cdot \frac{r^2}{r^2+d^2},$$

where S is the area of the effusion hole, p and T denote the pressure and temperature of the ion inside the furnace. The equilibrium constant K_2 is therefore given by the relation

$$K_2 = \frac{p_{M^+}p_{X^-}}{p_{MX}} = \frac{2\pi kT}{e^2S^2}\left(\frac{r^2+d^2}{r^2}\right)^2 \frac{i^+i^-}{p_{MX}} \sqrt{m_{M^+}m_{X^-}} \quad \ldots \quad (9)$$

All the quantities occurring in this equation can be experimentally measured or are otherwise known, and hence K_2 can be calculated. Then using this value of K_2 and substituting the values of the other quantities in (6) Q is found out.

There is however some uncertainty in the value of the pressure of the halide vapour in the main furnace. It may be remarked that in all the theoretical or experimental work so far undertaken, the assumed values of this vapour pressure were quite uncertain, being obtained by extrapolation far

beyond the range of observations (most often extrapolated from the liquid state to the solid state). The error in p due to this cause has been variously estimated between 50% and 500%. Thanks however to the work of J. E. Mayer and I. H. Wintner (1938) the vapour pressure of some alkali halides are now known with certainty in the desired region and these have been utilized in this paper. The vapour pressure has been calculated from the equation

$$\log_{10} p = -\frac{A}{T} - 3 \log_{10} \frac{T}{1000} + C,$$

where the values given by Mayer and Wintner for the constants A and C have been substituted. This however gives the vapour pressure in the auxiliary furnace from which we have to calculate the vapour pressure of the salt in the main furnace. At such low pressure these two vapour pressures will be different. It is the case of a tube of varying diameter and having a temperature gradient. In this case it is not possible to obtain an absolutely rigorous expression for the pressure difference between the ends of the tube. Knudsen (1927) has studied the phenomenon in considerable detail and has obtained semi-empirical formulæ which are valid over limited ranges of the ratio of tube diameter to free path. He has shown that for a circular uniform tube, the relation connecting p and T along the tube must be of the form

$$\frac{dp}{dT} = \frac{p}{T} \phi \left(\frac{r}{\lambda}\right), \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

where r is the radius of the tube and λ the mean free path. In the general case $\phi(r/\lambda)$ is a complicated function of r/λ involving several empirical constants; when however r/λ is small in comparison to 1, $\phi(r/\lambda)$ assumes the form

$$1/2 \left(1 + \frac{2ar}{\lambda}\right)$$

where a is some empirical constant for the gas. In order to obtain the correct value for the pressure difference one should express λ as a function of p and T and substitute this in (10) and integrate. This is hardly possible here since λ cannot be expressed correctly as a function of p and T and the empirical constants will also be different, depending upon the gas and the tube. Further, in our case r has not the same value at all places. The pressure cannot therefore be determined accurately and we can as a rough approximation assume that it is given by the full Knudsen effect, i.e. $p_1/p_2 = \sqrt{T_1/T_2}$, a value given by (10) when $r/\lambda \rightarrow 0$. In these experiments λ is generally several times greater than r and hence this assumption is not far wrong. In any case the pressure p_1 must lie between p_2 and $p_2\sqrt{T_2/T_1}$ and the maximum error in p_1 cannot exceed 40% and the resulting error in Q barely exceeds 1%. There is however yet another uncertainty in p_1 for the above formula holds for a non-dissociating gas. In the present case the phenomenon is complicated by the dissociation of the vapour into various

components (equations 1–5) but since the degree of dissociation is small the above result will not be much affected and in the present paper all such effect will be neglected. This point will however be separately discussed theoretically in a subsequent paper.

Experimental Procedure.

First the graphite tube was thoroughly degassed by prolonged intermittent heating for several hours after which the blank currents from the empty tube diminish to a negligible value. Then the salt was introduced and the furnace heated. When the steady state was attained the currents were measured at 2 volts with different currents through the electromagnet and for purposes of calculation the constant values of the negative and positive currents were utilized. It was however found that the temperature of the graphite furnace is not quite uniform as is evident from the manner of heating. The temperature at the centre is practically constant over a large length but falls appreciably near the ends. Thus to some extent the problem is analogous to the phenomenon of dissociation under a temperature gradient which has been discussed by Dirac (1924) under ordinary pressures, but his analysis will not be applicable to this case since here the pressure is very low. We will however neglect the effect of the temperature gradient and simply take the mean temperature of the graphite tube for our calculations. The procedure is approximately justified since the temperature gradient is small and extends over a small region. For this purpose the temperature of the graphite tube was measured at several places and the average calculated. This is however the chief source of error, since errors in T by a few per cent affect Q to the same extent. In view of this uncertainty we shall neglect the very slight difference of temperature (about 5 or 10°) between the inside and outside of the graphite tube as shown by Powell and Schofield (1939) and also the difference between the true temperature and the blackbody temperature of the graphite tube as the emissivity of the latter is quite high.

The experimental results obtained with RbCl and RbBr are tabulated below (Tables 1 and 2). The salts were recently supplied by Scherring-Kahlbaum and were extra pure and anhydrous. The experiments were repeated at different times and practically consistent results were always obtained.

Rubidium Chloride.

Diameter of effusion hole = 1·93 mm.

Radius of the limiting diaphragm = 0·42 cm.

Accelerating potential = 2 volts.

Current sensitivity of the galvanometer = $1{\cdot}59\times10^{-9}$ amp./mm.

TABLE 1.

Mean temperature of graphite furnace in °C.	Temperature of auxiliary furnace in °K.	Vapour pressure of salt in auxiliary furnace in dynes/cm.^{2}	Distance between effusion hole and limiting diaphragm in mm.	Current through electromagnet in amps.	Negative deflection in mm.	Positive deflection in mm.	$K_2 \times 10^6$ in dynes/cm.^{2}	Q in kilocals.
1440	871	11·27	20·5	0	142×3	95	12·77	115·2
				1	82×3			
				4	74×3			
				5, 6	73×3			
1470	878	14·50	,,	0	71×10	55×3	28·22	114·4
				1	152×3			
				4	131×3			
				5	125×3			
				6	120×3			
				7	118×3			
1495	881	15·73	,,	0	98×10	69×3	39·92	114·9
				1	167×3			
				4	155×3			
				5	149×3			
				6	144			
				7	143×3			
1540	893	22·86	,,	0	320×10	112×3	101·7	114·5
				1	162×10			
				4	127×10			
				5	112×10			
				6	340×3			
				7	325×3			
				8	320×3			
1380	879	14·78	21·0	0	210	62	4·775	114·3
				1	160			
				4	153			
				5, 6	152			
1405	888	19·79	,,	0	125×3	98	9·012	114·0
				1	280			
				4	245			
				5	241			
				6	240			
1420	889	20·18	,,	0	148×3	105	11·7	114·1
				1	108×3			
				6, 7	98×3			
1480	904	31·85	,,	0	91×10	63×3	26·04	115·3
				1	230×3			
				6	189×3			
				7	187×3			
1450	899	26·94	,,	0	245×3	132	17·62	114·8
				1	185×3			
				7	155×3			

Mean temperature of graphite furnace in °C.	Temperature of auxiliary furnace in °K.	Vapour pressure of salt in auxiliary furnace in dynes/cm².	Distance between effusion hole and limiting diaphragm in mm.	Current through electro-magnet in amps.	Negative deflection in mm.	Positive deflection in mm.	$K_2 \times 10^6$ in dynes/cm.²	Q in kilocals.
1440	893	22·86	21·0	0	185×3	110	12·98	115·1
				1	145×3			
				4	128×3			
				5	122×3			
				6	118×3			
				7	117×3			
1425	888	19·79	,,	0	164×3	92	12·55	114·2
				1	130×3			
				4	120×3			
				5, 6	118×3			

Mean Q = 114·6 Kcal.

Lattice Energy = 114·6+51·3 = 165·9 Kcal.

Rubidium Bromide.

Diameter of the effusion hole = 1·93 mm.

Distance between effusion hole and limiting diaphragm = 19·5 mm.

Table 2.

Temperature of graphite furnace in °C.	Temperature of auxiliary furnace in °K.	Vapour pressure of salt in auxiliary furnace in dynes/cm.²	Current through electro-magnet in amps.	Negative deflection in mm.	Positive deflection in mm.	$K_2 \times 10^5$ in dynes/cm.²	Q in kilocals.
1405	842	6·680	0	132×3	143	5·449	107·9
			1	125×3			
			4	320			
			7	305			

Temperature of graphite furnace in °C.	Temperature of auxiliary furnace in °K.	Vapour pressure of salt in auxiliary furnace in dynes/cm.^{2}	Current through electro-magnet in amps.	Negative deflection in mm.	Positive deflection in mm.	$K_2 \times 10^6$ in dynes/cm.^{2}	Q in kilocals.
1420	844	7·109	0 1 4 7	142×3 127×3 112×3 110×3	52×3	6·077	108·3
1370	834	5·213	0 1 4 7	280 217 200 197	85	2·640	107·6
1440	860	12·23	0 1 4 7	335×3 275×3 242×3 220×3	75×3	10·23	105·4
1480	898	39·88	0 1 4 5 7	167×10 148×3 119×3 116×3 114×10	83×10	20·89	107·9
1435	885	26·92	0 1 4 7	133×10 121×10 117×10 108×10	63×10	21·81	104·9
1405	875	19·71	0 1 4 7	84×10 77×10 65×10 62×10	43×10	11·51	105·2
1390	866	15·08	0 1 4 7	175×3 148×3 133×3 124×3	91×3	5·675	106·6
1345	850	8·76	0 1 4 7	238 200 170 165	100	1·551	107·7
1355	854	10·14	0 1 4 7	90×3 75×3 65×3 63×3	120	1·852	107·9

Mean Q = 106·9 Kcal.

Lattice energy = 106·9+51·2 = 158·1 Kcal.

Electron affinity of bromine = $D+I_M-Q$ = 90·4+96·0−106·9 = 79·5 Kcal.

The various data utilized in this paper are given in Table 3, and are generally taken from Helmholtz and Mayer (1932) or Mayer and Wintner (1938).

TABLE 3.

Salt.	Moment of inertia of molecule in gaseous state $\times 10^{38}$ gm. cm.^{2}	Characteristic frequency of vibration of molecule in gaseous state in cm.$^{-1}$	Heat of dissociation into neutral atoms in Kcals.	Heat of sublimation at absolute zero in Kcals.	Heat of ionization of alkali in Kcals.
RbCl ..	2·78	253	....	51·3	96·0
RbBr ..	5·02	198	90·4	51·2	96·0

The value of the heat of dissociation of RbCl into its atoms as given by these authors, however, does not seem to be correct. There is considerable divergence in the recorded values of this quantity. The values are as follows:—Sommermeyer (1929) from spectroscopic experiments obtains $D > 90{\cdot}5$ while from chemical data he estimates it as 120 Kcal; Helmholtz and Mayer from thermo-chemical data put $D = 97{\cdot}4$ while Helmholtz and Wintner's recent estimate is 101·5. Under the circumstances it appears better to assume the value of the electron affinity of chlorine, a quantity better known in various ways, and then use this value to find D from equation (7). Assuming E_X for $Cl = 86{\cdot}0$ we get $D = 104{\cdot}6$ Kcal, a value which the author considers quite probable since it is expected to be greater than the corresponding quantity for KCl for which the average recorded value appears to be about 101 Kcal. It may be worth while to remark that this uncertainty in the value of D does not cause any error in the value of the heat of ionic dissociation or the lattice energy.

DISCUSSION OF RESULTS.

For the sake of comparison with other determinations the values of the heat of ionic dissociation, the lattice energy and the electron affinity of the halogen as obtained in this paper are recorded in Table 4 along with other known values. The results obtained here are seen to be in general agreement with other determinations.

The chief sources of error in the experiment are the non-uniformity in the temperature of the graphite tube, the error in the determination of temperature by the optical pyrometer, the uncertainty in the assumed values of the vibration frequency and the moment of inertia, the actual vapour pressure in the main furnace, etc. The error due to all these causes combined is not likely to exceed ± 3 Kcals in the value of Q.

TABLE 4.

	Rubidium Chloride.			Rubidium Bromide.		
	Heat of dissociation in Kcal.	Lattice energy in Kcal.	Electron affinity of chlorine in Kcal.	Heat of dissociation in Kcal.	Lattice energy in Kcal.	Electron affinity of bromine in Kcal.
Experimental :						
Present author ..	114·6	165·9	..	106·9	158·1	79·5
Helmholtz & Mayer (1934)	..	..	..	102·3*	$151{\cdot}3 \pm 4$	84·2
Saha & Tandon (1936) ..	..	..	86·6	..	..	..
Tandon (1937) ..	..	..	..	..	..	80·0
Angerer & Müller (1925)..	..	..	86·6 } 89·6 }	..	..	79·1 } 81·3 }
Goldstein (1938) ..	..	..	85·2	..	..	..
Theoretical :						
Helmholtz & Mayer (1932)	107·7	160·7	86·5 (mean)	104·5	153·5	81·5 (mean)
Huggins (1937) ..	110·7	162·0	86·0* (mean)	104·9	156·1	79·5* (mean)
Mayer & Wintner (1938)	109·4	..	88·1*	102·3	..	84·1*

* Values calculated by me from their results.

In conclusion I wish to express my sincere thanks to Prof. M. N. Saha, F.R.S., for his valuable guidance throughout the work. Our thanks are also due to the Royal Society of London for giving a grant which enabled us to construct the furnace and buy its accessories.

SUMMARY.

The thermal dissociation of RbCl and RbBr vapours into their ions has been experimentally investigated in the temperature region 1350–1550°C. with the help of an apparatus already described by the author elsewhere. The concentrations of the positive alkali ion, the negative halogen ion and the electron inside the furnace have been measured and from these the equilibrium constant of ionic dissociation at different temperatures has been deduced. A theoretical formula then enables us to calculate the heat of ionic dissociation of the salt, the values obtained being 114·6 Kcal for RbCl and 106·9 Kcal for RbBr. The lattice energies come out to be 165·9 Kcal for RbCl and 158·1 Kcal for RbBr. Using Born cycle we get from these measurements the value of the electron affinity of bromine to be 79·5 Kcal and the heat of dissociation (atomic) of RbCl equal to 104·6 Kcal. These results in general agree with other known determinations.

REFERENCES.

Angerer and Müller, 1925, *Phys. Zeits*, **26**, 643.
Born, M. and Mayer, J. E., 1932, *Zs. f. Phys.*, **75**, 1.
Dirac, P. A. M., 1924, *Proc. Camb. Phil. Soc.*, **22**, 132.
Glockler, G., 1934, *Phys. Rev.*, **46**, 111.
Goldstein, L., 1938, *Annales de Phy.*, **9**, 723.
Helmholtz, L. and Mayer, J. E., 1932, *Zs. f. Phys.*, **75**, 19.
Mayer, 1934, *Jour. Chem. Phys.*, **2**, 245.
Huggins, M. L., 1937, *Jour. Chem. Phys.*, **5**, 142.
Knudsen, M., 1927, *Ann. d. Phys.*, **83**, 797.
Mayer, J. E., 1930, *Zs.f. Phys.*, **61**, 798.
Mayer, J. E., and Wintner, I. H., 1938, *Jour. Chem. Phys.*, **6**, 301.
Powell, R. W. and Schofield, F. H., 1939, *Proc. Phys. Soc.*, **51**, 153.
Saha, M. N. and Tandon, A. N., 1936, *Proc. Nat. Acad. Sci. India*, **6**, 212.
———, 1937, *Proc. Nat. Inst. Sci. India*, **3**, 287.
Sommermeyer, K., 1929, *Zs. f. Phys.*, **56**, 548.
Srivastava, B. N., 1938, *Proc. Nat. Inst. Sci. India*, **4**, 365.
Tandon, A. N., 1937*a*, *Ind. Jour. Phys.*, **11**, 99.
———, 1937*b*, *Proc. Nat. Acad. Sci. India*, **7**, 102.

ABSORPTION OF ELECTROMAGNETIC WAVES IN THE EARTH'S ATMOSPHERE.

By R. R. Bajpai, *M.Sc. and* K. B. Mathur, *M.Sc., Department of Physics, The University, Allahabad.*

(Communicated by Prof. M. N. Saha, F.R.S.)

(*Received April 22nd, 1939.*)

Introduction.

The problem of absorption of radio waves in the upper atmosphere has been attacked by several workers. Actual numerical calculations of the values of refractive indices and absorption coefficients for the two magneto-ionic components have been carried out by Goubau (1935) for Munich and by Taylor (1934) for Slough. Martyn (1934) has done the same for magnetic latitudes of 0°, 45° and 90°. Analytically the problem has been examined by Booker (1935), Toshniwal (1936) and others (1936); but these authors have restricted their treatments to values of θ (the angle between the direction of propagation and the Earth's magnetic field) between certain limits. The object of the present paper is to give an analytical treatment of general applicability and to show that for certain latitudes results contrary to those expected before may be obtained.

The notations used are

$p_h = \frac{eh}{mc}$, Larmor frequency

$p_{x,y,z} = \frac{eh_{x,y,z}}{mc}$, components of Larmor frequency

p = pulsatance of electromagnetic waves

N = number of electrons per cu. cm.

$$p_o^2 = \frac{4\pi Ne^2}{m}$$

ν = collisional frequency, *i.e.* the number of times an electron collides with a neutral particle per second.

$$\omega = \frac{p_h}{p}$$

$$\omega_{x,y,z} = \frac{p_{h(x,y,z)}}{p}$$

$$r = \frac{p_o^2}{p^2}$$

$$\delta = \frac{\nu}{p}$$

$$\beta = 1 - i\delta$$

$q = \mu - \dfrac{ick}{p}$, complex refractive index

k = absorption coefficient

e = charge on an electron

m = mass of an electron

c = velocity of light in vacuo.

The suffixes o and x denote quantities pertaining to the ordinary and the extraordinary waves respectively. We start from equation (3.1) of paper 1 (1938), but we shall make the result more general by putting

$$\phi = p\left(t \pm \frac{1}{c}\int q\,dz\right)$$

We are using q in place of μ of the previous paper.

We get from equations (2.14) of the same paper

$$\begin{aligned} qA &= D \\ qB &= -C \\ qC &= -iLA - K_2 B \\ qD &= K_1 A - iLB \end{aligned}$$

exactly as in relations (3.2) of paper 1, and the remaining treatment is identical. We get, corresponding to (3.5),

$$\left.\begin{aligned} q_o^2 &= K_{11} - L\rho_o \\ q_x^2 &= K_{22} - L\rho_x \end{aligned}\right\} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (1)$$

where $$K_{11} = 1 - r\,\frac{\beta^2 - r\beta - \omega_x^2}{C'}$$

$$K_{22} = 1 - r\,\frac{\beta^2 - r\beta}{C'}$$

$$L = \frac{r\omega_z(r - \beta)}{C'}$$

$$C' = \beta(\beta^2 - \omega^2) - r(\beta^2 - \omega_z^2)$$

$$\rho_o = f\left[1 - \sqrt{1 + \frac{1}{f^2}}\,\right]$$

$$\rho_x = f\left[1+\sqrt{1+\frac{1}{f^2}}\,\right]$$

$$f = \frac{K_{11}-K_{22}}{2L}.$$

It can be easily shown that the refractive indices for the two magnetoionic components are given by

$$\left.\begin{aligned} q_o^2 &= \frac{(r-\beta)(\omega^2+r\beta-\beta^2)-\frac{r}{2}\,\omega_x^2\left[1-\sqrt{1+\left\{\frac{2(r-\beta)\,\omega_z}{\omega_x^2}\right\}^2}\,\right]}{\beta(\beta^2-\omega^2)-r(\beta^2-\omega_z^2)} \\ q_x^2 &= \frac{(r-\beta)(\omega^2+r\beta-\beta^2)-\frac{r}{2}\,\omega_x^2\left[1+\sqrt{1+\left\{\frac{2(r-\beta)\,\omega_z}{\omega_x^2}\right\}^2}\,\right]}{\beta(\beta^2-\omega^2)-r(\beta^2-\omega_z^2)} \end{aligned}\right\}\quad \ldots \quad (2)$$

These expressions have been deduced in different ways by Appleton (1932), Hartree (1929) and Försterling and Lassen (1933). They can also be put as

$$\left.\begin{aligned} q_o^2 &= 1+\frac{2r}{-2\beta-\frac{\omega_x^2}{r-\beta}+\sqrt{\frac{\omega_x^4}{(r-\beta)^2}+4\omega_z^2}} \\ q_x^2 &= 1+\frac{2r}{-2\beta-\frac{\omega_x^2}{(r-\beta)}-\sqrt{\frac{\omega_x^4}{(r-\beta)^2}+4\omega_z^2}} \end{aligned}\right\}\quad \ldots \quad \ldots \quad (2)$$

and this is the form in which they have been generally discussed.

Since $\beta = 1-i\,\frac{\nu}{p}$, we can split up q_o^2 and q_x^2 into real and imaginary parts. We may put q in the form

$$q = \mu - i\,\frac{ck}{p}$$

so that the wave is given by

$$y = Ae^{-\int k dz}\, e^{ip(t-\frac{1}{c}\int \mu dz)}.$$

Now the general expressions for k and μ are rather complicated. We first try some simple cases and hence derive results of general application.

Case I.

$$\left[\frac{2(r-\beta)\omega_z}{\omega_x^2}\right]^2 << 1 \qquad \text{(Quasi-transverse).}$$

Under the above condition, equations (2) reduce to

$$q_o^2 = 1-\frac{r}{\beta}$$

$$q_x^2 = 1-\frac{r}{\beta-\frac{\omega_x^2}{\beta-r}}.$$

We rewrite them as

$$\left.\begin{aligned} q_o^2 &= 1-\frac{r}{1+\delta^2}-i\,\frac{r\delta}{1+\delta^2} \\ q_x^2 &= 1-\frac{R}{1+D^2}-i\,\frac{RD}{1+D^2} \end{aligned}\right\} \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

where

$$R = \frac{r}{1+\dfrac{(r-1)\omega_x^2}{(r-1)^2+\delta^2}}\,, \quad D = \delta\,\frac{1+\dfrac{\omega_x^2}{(r-1)^2+\delta^2}}{1+\dfrac{\omega_x^2(r-1)}{(r-1)^2+\delta^2}}\,.$$

From (3) it can be easily deduced that

$$\mu_o^2 = \frac{1}{2}\left\{\sqrt{\left(1-\frac{r}{1+\delta^2}\right)^2+\left(\frac{r\delta}{1+\delta^2}\right)^2}+\left(1-\frac{r}{1+\delta^2}\right)\right\} \quad \ldots \quad (4)$$

$$\frac{c^2k_o^2}{p^2} = \frac{1}{2}\left\{\sqrt{\left(1-\frac{r}{1+\delta^2}\right)^2+\left(\frac{r\delta}{1+\delta^2}\right)^2}-\left(1-\frac{r}{1+\delta^2}\right)\right\} \quad \ldots \quad (5)$$

$$\mu_x^2 = \frac{1}{2}\left\{\sqrt{\left(1-\frac{R}{1+D^2}\right)^2+\left(\frac{RD}{1+D^2}\right)^2}+\left(1-\frac{R}{1+D^2}\right)\right\} \ldots \quad (6)$$

$$\frac{c^2k_x^2}{p^2} = \frac{1}{2}\left\{\sqrt{\left(1-\frac{R}{1+D^2}\right)^2+\left(\frac{RD}{1+D^2}\right)^2}-\left(1-\frac{R}{1+D^2}\right)\right\} \ldots \quad (7)$$

We easily notice that the above expressions for $\mu_{o,x}$ and $k_{o,x}$ are respectively of the forms

$$\mu^2_{o,x} = \tfrac{1}{2}\left\{\sqrt{X^2_{o,x}+Y^2_{o,x}}+X_{o,x}\right\}$$

$$\frac{c^2\,k^2_{o,x}}{p^2} = \tfrac{1}{2}\left\{\sqrt{X^2_{o,x}+Y^2_{o,x}}-X_{o,x}\right\}$$

where

$$X_o = 1-\frac{r}{1+\delta^2} \quad Y_o = \frac{r\delta}{1+\delta^2}$$

$$X_x = 1-\frac{R}{1+D^2} \quad Y_x = \frac{RD}{1+D^2}\,.$$

These forms clearly show that neither $\mu^2_{o,x}$ nor $\dfrac{c^2\,k^2_{o,x}}{p^2}$ can ever be zero, unless δ is zero. We, of course, neglect the case of $r = 0$, when we will have $k^2_{o,x} = 0$ and $\mu_{o,x} = 1$.

When $\delta = 0$, $k_{o,x} = 0$, $\mu_o^2 = 1-r$ and $\mu_x^2 = 1-R$.

But as long as δ is greater than zero these expressions have definite positive values. We also observe that so long as X is positive

$$\mu^2_{o,x} > \frac{c^2\,k^2_{o,x}}{p^2}$$

but when X becomes negative

$$\mu^2_{o,x} < \frac{c^2 k^2_{o,x}}{p^2}.$$

Case II.

$$\left[\frac{2(r-\beta)\,\omega_z}{\omega_x^2}\right]^2 >> 1 \qquad \text{(Quasi-longitudinal).}$$

Equations (2), under this condition, reduce to

$$q_o^2 = 1 - \frac{r}{\beta + |\omega_z|}$$

$$q_x^2 = 1 - \frac{r}{\beta - |\omega_L|}.$$

We rewrite the above equations as

$$q_o^2 = 1 - \frac{r(1+|\omega_z|)}{(1+|\omega_z|)^2+\delta^2} - i\,\frac{r\delta}{(1+|\omega_z|)^2+\delta^2} \qquad \text{.. (8)}$$

$$q_x^2 = 1 - \frac{r(1-|\omega_z|)}{(1-|\omega_z|)^2+\delta^2} - i\,\frac{r\delta}{(1-|\omega_z|)^2+\delta^2} \qquad \text{.. (9)}$$

Hence

$$\mu_o^2 = \frac{1}{2}\left\{\sqrt{\left[1-\frac{r(1+|\omega_z|)}{(1+|\omega_z|^2+\delta^2}\right]^2+\left[\frac{r\delta}{(1+|\omega_z|)^2+\delta^2}\right]^2} + \left[1-\frac{r(1+|\omega_z|)}{(1+|\omega_z|)^2+\delta^2}\right]\right\} \qquad \text{.. (10)}$$

$$\frac{c^2 k_o^2}{p^2} = \frac{1}{2}\left\{\sqrt{\left[1-\frac{r(1+|\omega_z|)}{(1+|\omega_z|)^2+\delta^2}\right]^2+\left[\frac{r\delta}{(1+|\omega_z|)^2+\delta^2}\right]^2} - \left[1-\frac{r(1+|\omega_z|)}{(1+|\omega_z|)^2+\delta^2}\right]\right\} \qquad \text{.. (11)}$$

$$\mu_x^2 = \frac{1}{2}\left\{\sqrt{\left[1-\frac{r(1-|\omega_z|)}{(1-|\omega_z|)^2+\delta^2}\right]^2+\left[\frac{r\delta}{(1-|\omega_z|)^2+\delta^2}\right]^2} + \left[1-\frac{r(1-|\omega_z|)}{(1-|\omega_z|)^2+\delta^2}\right]\right\} \qquad \text{.. (12)}$$

$$\frac{c^2 k_x^2}{p^2} = \frac{1}{2}\left\{\sqrt{\left[1-\frac{r(1-|\omega_z|)}{(1-|\omega_z|)^2+\delta^2}\right]^2+\left[\frac{r\delta}{(1-|\omega_z|)^2+\delta^2}\right]^2} - \left[1-\frac{r(1-|\omega_z|)}{(1-|\omega_z|)^2+\delta^2}\right]\right\} \qquad \text{.. (13)}$$

These expressions also are of the same form as that of the expressions derived in the previous case and we can write them as

$$\mu^2_{o,x} = \frac{1}{2}\left\{\sqrt{P^2_{o,x}+Q^2_{o,x}} + P_{o,x}\right\}$$

$$\frac{c^2k^2_{o,x}}{p^2} = \frac{1}{2}\left\{\sqrt{P^2_{o,x}+Q^2_{o,x}}-P_{o,x}\right\}$$

where

$$P_o = 1-\frac{r(1+|\omega_z|)}{(1+|\omega_z|)^2+\delta^2} \qquad Q_o = \frac{r\delta}{(1+|\omega_z|)^2+\delta^2}$$

$$P_x = 1-\frac{r(1-|\omega_z|)}{(1-|\omega_z|)^2+\delta^2} \qquad Q_x = \frac{r\delta}{(1-|\omega_z|)^2+\delta^2}.$$

Obviously, $k_{o,x} = 0$ only when either $r = 0$ or $\delta = 0$. In the former case ($r = 0$), $\mu_{o,x}$ become unity while in the latter case ($\delta = 0$)

$$\mu_o^2 = 1-\frac{r}{1+|\omega_z|}$$

$$\mu_x^2 = 1-\frac{r}{1-|\omega_z|}.$$

We are however interested in the propagation of radio waves in the ionosphere where neither r is zero nor δ is zero. Hence under these conditions none of the four quantities $\mu_{o,x}$ and $k_{o,x}$ ever becomes zero; so long as p is positive

$$\mu^2_{o,x} > \frac{c^2k^2_{o,x}}{p^2}$$

but when p becomes negative

$$\mu^2_{o,x} < \frac{c^2k^2_{o,x}}{p^2}.$$

§ 2.

We shall divide absorption into two regions, viz., the non-reflecting lower region (where the density of electrons is very small) and the reflecting region where the value of the refractive index becomes very small. We have now to find out whether the propagation of waves in the above two regions is governed by Case I or Case II and how it depends on θ, the magnetic latitude.

The condition

$$\left[\frac{2(r-\beta)\omega_z}{\omega_x^2}\right]^2 = 1$$

which divides the two cases may be put in a more convenient form.

Let us put

$$p_\theta^{2*} = \frac{1}{4}\frac{p_x^4}{p_z^2}.$$

* This p_θ is the critical collisional frequency first pointed out by Appleton and Builder (1933). Its value at Allahabad is 3×10^6. The quantity under the square root in the expressions for $q^*_{o,x}$ is

Then the above condition becomes

$$\left[\frac{r-\beta}{p_\theta}\right]^2 = 1.$$

Since $r-\beta = r-1+i\delta$, a complex quantity, we can put it in the form

$$\left[\frac{(r-1)^2+\delta^2}{p_\theta^2} e^{2i\phi}\right] = 1$$

where $\phi = \tan^{-1}\cdot\dfrac{\delta}{r-1}$.

We can now take the above condition to be

$$(r-1)^2+\delta^2 = p_\theta^2$$

or

$$(p^2-p_o^2)^2+p^2\nu^2 = p^2 p_\theta^2 \quad \ldots \quad \ldots \quad \ldots \quad (14)$$

This condition is the same as that given by Booker (*loc. cit.*, eqn. (31)).

Note on the Curves.

Fig. (1) * gives the assumed variation of p_o, N and ν with height. It is only a crude picture of the atmosphere, but is expected to give fairly approximate results for the E-region. Figs. (2) and (3) represent curves given by equation (14). In drawing these curves the values of p_o and ν have been read from fig. (1). p_h has been assumed to be 8×10^6. Fig. (2) is a representative of the class of frequencies greater than the gyromagnetic frequency, while fig. (3) represents frequencies below the above-mentioned frequency. They have been actually drawn for $p = 2{\cdot}5\times10^7$ ($\lambda = 75{\cdot}36m.$) and $p = 5\times10^6$ ($\lambda = 376{\cdot}8m$) respectively. Fig. (4) is another representative of medium waves and is drawn for $p = 7\times10^6$ ($\lambda = 264{\cdot}14m$). Fig. (5) is drawn for $p = 10^6$ ($\lambda = 1884m$) and thus represents propagation of long waves. Fig. (6) is drawn for $p = 5\times10^7$ ($\lambda = 37{\cdot}68m$) on the assumption that collision frequency remains constant at 10^3. It is meant to give an approximate idea of the conditions of propagation in the F-region. The curves hold for both the hemispheres and it is evident from them that,

---

$$1+\left[\frac{2(r-\beta)\omega_z}{\omega_x^2}\right]^2 = 1+\left[\frac{r-\beta}{p_\theta}\right]^2 = 1+\frac{(r-1)^2-2i\delta(r-1)-\delta^2}{p_\theta^2}$$

and this becomes zero when $r=1$ and $r=p_\theta$, so that q_o becomes equal to q_x. But this condition holds only under a severe limitation, for we must have a region where $r=1$, and $\nu = p_\theta$.

* It is the same as assumed by Booker (*loc. cit.*).

in general, quasi-transverse type of propagation is of importance only at medium frequencies (except of course a very narrow region near about the magnetic equator where it holds at all frequencies) and that it is the quasi-longitudinal type which predominates at long and short waves.

We further observe that so far as the non-reflecting region is concerned (where the value of electron density is small), we can divide the whole surface of the earth into two regions, viz., (*a*) places not very near the magnetic equator and (*b*) places very near the magnetic equator. It is easy to see that in the former region both the *o*- and the *x*-waves of every frequency are propagated according to Case II but that in the latter region their propagation is governed by Case I. Again when we consider propagation in the reflecting region three cases arise. A concise description of the features of the various cases is given in Table 1 and their applicability has been discussed afterwards.

TABLE 1.

Name of Case	Definition
Case I (Quasi-transverse)	$(p^2-p_o^2)^2+p^2\nu^2<<p^2p_\theta^2$
Case II. (Quasi-longitudinal)	$(p^2-p_o^2)^2+p^2\nu^2>>p^2p_\theta^2$
Case A*	Propagation of both the *o*- and the *x*-wave governed by Case I.
Case B*	Propagation of *o*-wave governed by Case I but that of *x*-wave by Case II.
Case C*	Propagation of both the *o*- and the *x*-wave governed by Case II.

Case A.—Propagation of both the magneto-ionic components is governed by Case I. On short and long waves this holds for rather small values of θ, the magnetic latitude or the angle of dip, but on medium waves it may hold even up to 25° or so as is evident from figs. (3) and (4). We shall, however, term this region as the magnetic equatorial latitudes and for evaluating k_o and k_x in these latitudes we shall make use of eqns. (5) and (7) respectively.

* These cases refer to the reflecting region only.

Case B.—These are the latitudes where propagation of the x-wave is governed by Case II (quasi-longitudinal) while that of the o-wave by Case I (quasi-transverse). These conditions will hold good at places where the magnetic latitudes are neither too high nor too low. It is not possible to give definite values of these latitudes in any of these cases, for they depend on the frequency of the wave under consideration, as is evident from a comparison of the various figures. This region we shall call intermediate magnetic latitude. For finding out the values of k_o and k_x in these latitudes we shall use eqns. (5) and (13) respectively.

Case C.—This is the region where both the o- and x-waves propagate according to Case II. For short waves these conditions exist in the higher magnetic latitudes, i.e., places near the magnetic poles but for medium waves they may exist in magnetic latitudes as low as 30° as shown in figs. (3) and

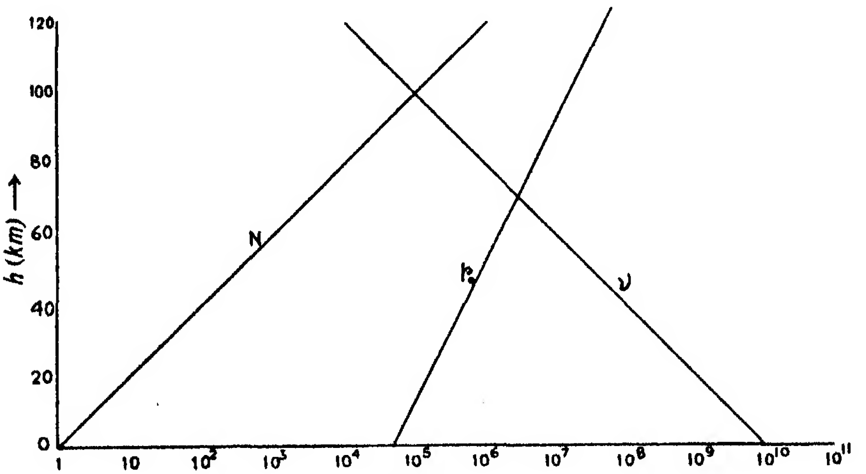


FIG. 1.

(4) and for long waves they may be fulfilled down to still lower latitudes as is evident from fig. (5).

ABSORPTION IN THE NON-REFLECTING REGION.

(*a*) *Places not very near the magnetic equator.*

We have already seen that in this region conditions of propagation are governed according to Case II. Hence, since r is small, we have from (11) and (13) as a first approximation

$$\frac{ck_o}{p}=\frac{1}{2}\frac{r\delta}{(1+|\omega_z|)^2+\delta^2}$$

$$\frac{ck_x}{p}=\frac{1}{2}\frac{r\delta}{(1-|\omega_z|)^2+\delta^2}\,.$$

Substituting for r, ω_z and δ, we get

$$k_o = \frac{2\pi e^2}{mc} \frac{N\nu}{(p + |p_z|)^2 + \nu^2} \quad \ldots \quad (15)$$

$$k_x = \frac{2\pi e^2}{mc} \frac{N\nu}{(p - |p_z|)^2 + \nu^2} \quad \ldots \quad (16)$$

Hence

$$\frac{k_o}{k_x} = \frac{(p - |p_z|)^2 + \nu^2}{(p + |p_z|)^2 + \nu^2} < 1 \quad \ldots \quad (17)$$

It is obvious from the above expression that at a particular level in this region the o-wave suffers less absorption than the x-wave. The difference in the relative absorption of the two waves becomes greater and greater both as we go towards the magnetic poles and as we consider frequencies approaching

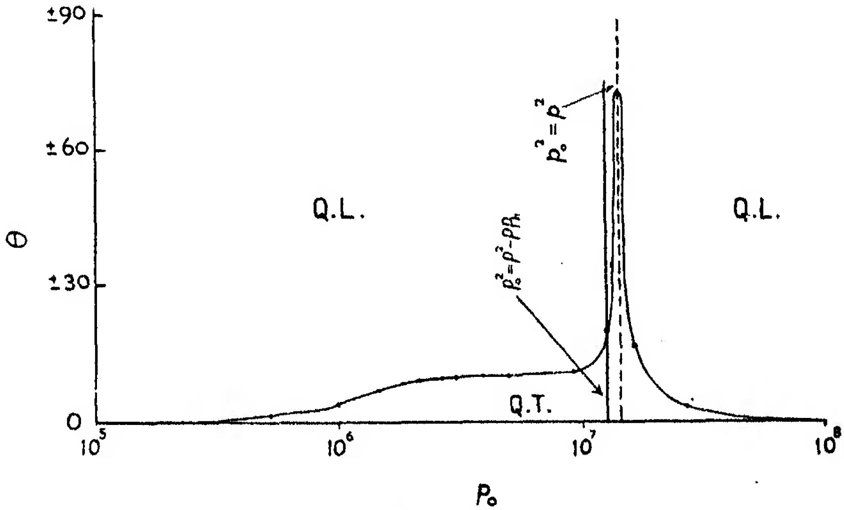


FIG. 2. Variation of Q.T. and Q.L. regions with θ for $p = 2\cdot5 \times 10^7$.

p_z. We can also say from (17) that in this region at places not very far from the magnetic equator the o-wave will be only slightly less absorbed than the x-wave, provided we confine our attention only to waves well away from p_z. We further observe from (15) and (16) that k_o has got a unique maximum at the level where $\nu = p + |p_z|$, while k_x has the same in the region given by $\nu = p - |p_z|$. Thus if N varies slowly, the maximum absorption suffered by these waves in the non-reflecting region will be at the above mentioned two different levels; but as we proceed towards the magnetic equator the two levels come nearer and nearer till at places not far removed from the magnetic equator, both the waves suffer maximum absorption in the non-reflecting region at approximately the same level, which tends to show that they should be almost equally absorbed—a conclusion derived before.

For finding out the total absorption suffered by the waves in the non-deviating region we have to integrate (15) and (16). Thus the integrated absorption coefficients k_o' and k_x' are

$$k_o' = \frac{2\pi e^2}{mc}\int_0^z \frac{N\nu}{(p+\mid p_z \mid)^2+\nu^2}\,dz \quad \ldots \quad \ldots \quad \ldots \quad (18)$$

$$k_x' = \frac{2\pi e^2}{mc}\int_0^z \frac{N\nu}{(p-\mid p_z \mid)^2+\nu^2}\,dz \quad \ldots \quad \ldots \quad \ldots \quad (19)$$

Now we have to find out as to how N and ν vary with height. In the case of stable layers, Chapman (1931) worked out a formula for variation of

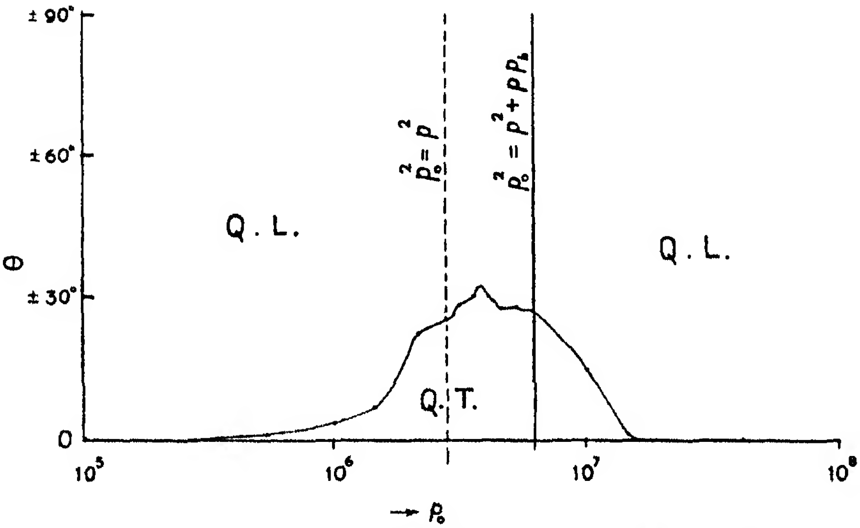


FIG. 3. Variation of Q.T. and Q.L. regions with θ for $p = 5 \times 10^6$.

N with height, on the supposition that electrons are produced by the absorption of monochromatic light. Saha and Rai (1938) have recently shown that this expression holds for continuous spectrum as well. We have according to these authors

$$N = N_o e^{\frac{1-z-e^{-z}\sec\chi}{2}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (20)$$

where

N = number of electrons per c.c.

N_o = number of electrons at the level h_o when $\chi = 0$

$$z = \frac{h-h_o}{H} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (21)$$

$$H = \frac{kT}{m'g} \quad \dots \quad (22)$$

χ = angle of incidence of solar radiation

k = Boltzmann's constant

T = absolute temperature

m' = mean molecular mass

g = acceleration due to gravity

h_o = the level where the ion production is maximum at the equator at equinox.

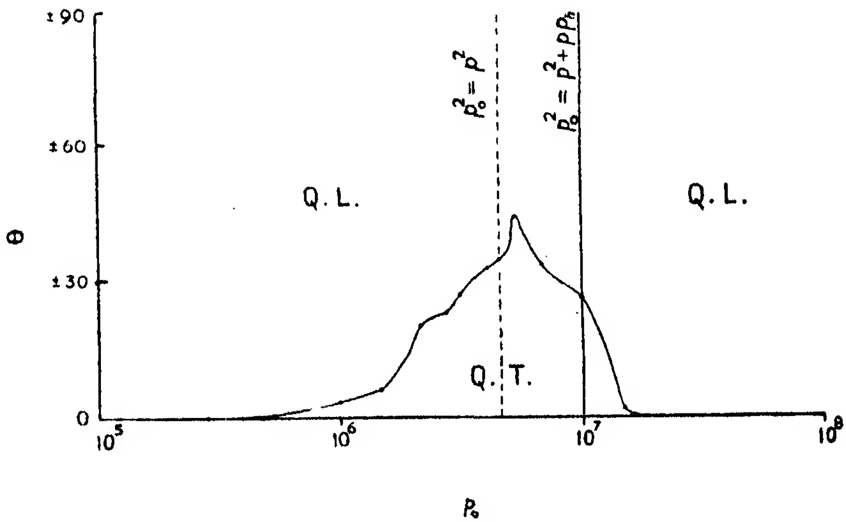


FIG. 4. Variation of Q.T. and Q.L. regions with θ for $p = 7 \times 10^6$.

As usual the height h is being measured from the datum level h_o and expressed in units of H, the height of equivalent atmosphere.

Again, we know that the frequency of collisions, ν, is given by

$$\nu = \frac{\bar{c}}{\lambda} \quad \dots \quad (23)$$

where

$\bar{c}$ = mean velocity of the particles (electrons in our case)

λ = mean free path of an electron.

We have from the kinetic theory of gases that

$$\bar{c} = \sqrt{\frac{8kT}{m\pi}}, \quad \lambda = \frac{4}{\sigma^2 n\pi}$$

where

m = mass of an electron

n = number of particles per c.c. with which electrons collide

σ = diameter of the particles.

So that (23) becomes

$$\nu = \sqrt{\frac{\pi k \sigma^4 T}{2m}}\, n \quad \ldots \quad (24)$$

Now if we assume that

$$n = n_o e^{-z}$$

we have for (24)

$$\nu = \sqrt{\frac{\pi k \sigma^4 T}{2m}}\, n_o e^{-z}$$

n_o being the number of particles per c.c. at the level h_o.

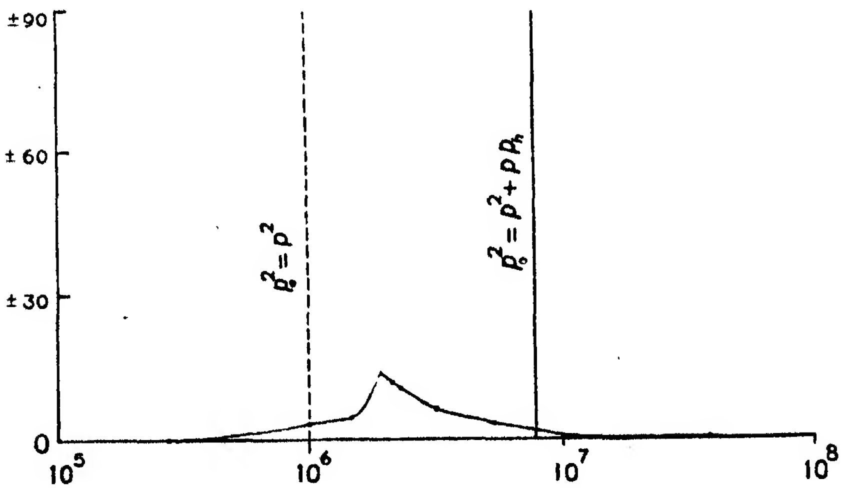


FIG. 5. Variation of Q.T. and Q.L. regions with θ for $p = 10^6$.

Putting $\nu_o = n_o \sqrt{\dfrac{\pi k \sigma^4 T}{2m}}$, we get

$$\nu = \nu_o e^{-z} \quad \ldots \quad (25)$$

Utilizing (22) and (25), we have for the integrated absorption of the waves, say in the E-region, if we are considering waves reflected from the F-region,

$$k_o' = \frac{2\pi e^2 N_o \nu_o}{mc} \int_{-\infty}^{+\infty} \frac{e^{\frac{1-8z-e^{-z}\sec\chi}{z}}}{(p + |p_z|)^2 + \nu_o^2 e^{-2z}}\, dz \quad \ldots \quad (26)$$

and

$$k_x' = \frac{2\pi e^2 N_o \nu_o}{mc} \int_{-\infty}^{+\infty} \frac{e^{\frac{1-3z-e^{-z}\sec\chi}{z}}}{(p-|p_z|)^2+\nu_o^2\, e^{-2z}}\, dz \quad \cdots \quad \cdots \quad (27)$$

These integrals have been solved by Appleton (1938). He deduces that

$$k'_{o,\,x} = \frac{2\pi N_o e^2 \nu}{mc}\left(\frac{e'}{\nu_o(p\pm|p_H|)}\right)^{\frac{1}{2}} X'$$

where

$$X' = \int_0^{\infty} \frac{t^{\frac{1}{2}}}{1+t^2}\, e^{-at}\, dt$$

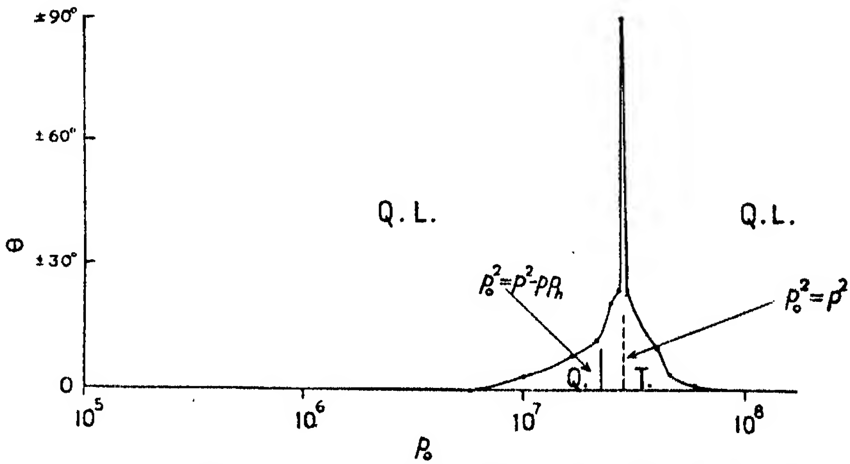


FIG. 6. Location of Q.T. and Q.L. regions with varying value of θ for $p = 5\times 10^7$.

and
$$a = \frac{p\pm|p_H|}{2\nu_o}\sec\chi$$

when
$$a >> 1$$

$$X' = \frac{1}{2}\sqrt{\frac{\pi}{a^3}}$$

when
$$a << 1$$

$$X' = \frac{\pi}{\sqrt{2}}(\cos a+\sin a) - 2\,\pi^{\frac{1}{2}}\, a\left(1-\frac{4}{15}a^2\right)+O(a^{\frac{5}{2}}).$$

When $a = 1$, he has found out the value of X', using integration by quadrature and has drawn a curve between X' and a.

(*b*) *Places very near the magnetic equator.*

We have already seen that at these places propagation of both the magneto-ionic components is governed by Case I (quasi-transverse). Hence we shall use equations (11) and (13) for evaluating the special absorption coefficients k_o and k_x respectively.

Since r is small, we have from the above equations as a first approximation

$$\frac{ck_o}{p} = \tfrac{1}{2}\,\frac{r\delta}{1+\delta^2} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (28)$$

and

$$\frac{ck_x}{p} = \tfrac{1}{2}\,\frac{RD}{1+D^2} = \tfrac{1}{2}\,\frac{r\delta}{\dfrac{\left(1-\dfrac{\omega_x^{\,2}}{1+\delta^2}\right)^2}{\left(1+\dfrac{\omega_x^{\,2}}{1+\delta^2}\right)^2}+\delta^2} \qquad \ldots \quad (29)$$

It is obvious from (28) and (29) that $k_o < k_x$ so that the o-wave suffers less absorption than the x-wave, but as for most of the useful waves the term

$$\left(1-\frac{\omega_x^{\,2}}{1+\delta^2}\right)^2 \Big/ \left(1+\frac{\omega_x^{\,2}}{1+\delta^2}\right)^2$$

is only slightly less than unity, the x-wave will be only slightly more absorbed than the o-wave. It will not be so for frequencies approaching p_x.

Substituting for r, δ, ω_x, etc. in (28) and (29), we get,

$$k_o = \frac{2\pi e^2}{mc}\cdot\frac{N\nu}{p^2+\nu^2} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (30)$$

and

$$k_x = \frac{2\pi e^2}{mc}\cdot\frac{N\nu}{p^2\dfrac{(p^2+\nu^2-p_x^{\,2})^2}{(p^2+p_x^{\,2}+\nu^2)^2}+\nu^2} \qquad \ldots \quad \ldots \quad (31)$$

Now using (22) and (25) we get for the integrated absorption of waves in a region that they traverse through,

$$k_o'' = \frac{2\pi e^2 N_o\nu_o}{mc}\int_{-\infty}^{+\infty}\frac{e^{\frac{1-3z-e^{-z}\sec\chi}{2}}}{p^2+\nu_o^2e^{-2z}}\,dz \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (32)$$

$$k_x'' = \frac{2\pi e^2 N_o\nu_o}{mc}\int_{-\infty}^{+\infty}\frac{e^{\frac{1-3z-e^{-z}\sec\chi}{2}}}{p^2\left[\dfrac{p^2-p_x^2+\nu_o^2e^{-2z}}{p^2+p_x^2+\nu_o^2e^{-2z}}\right]^2+\nu_o^2e^{-2z}}\,dz \qquad \ldots \quad (33)$$

(32) can be integrated as (28) and (29). The integration of (33) we do not propose to take up in this paper.

ABSORPTION IN THE REFLECTING REGION.

CASE A.—*Magnetic Equatorial Latitudes.*

It has been already shown that we have to use equations (5) and (7) in this case. Hence, expanding the right hand side of (5) and remembering that r is approximately unity for the o-wave in this region, we get, as a first approximation,

$$\frac{c^2k_o^2}{p^2}=\frac{1}{2}[\delta-\delta^2] \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (34)$$

the powers of δ higher than the second having been neglected.

Now in these latitudes $\omega \doteqdot \omega_x$ * and for frequencies greater than the gyromagnetic frequency the x-wave reflecting region is given by

$$r \doteqdot 1-\omega.$$

Making these substitutions and neglecting δ'^2 in comparison with ω^2 we get

$$R=\frac{r}{1+\dfrac{\omega_x^2(r-1)}{(r-1)^2+\delta^2}} \doteqdot \frac{1-\omega}{1-\dfrac{\omega\omega_x^2}{\omega^2}} \doteqdot 1$$

and

$$D=\delta'\,\frac{1+\dfrac{\omega_x^2}{(r-1)^2+\delta^2}}{1+\dfrac{\omega_x^2(r-1)}{(r-1)^2+\delta^2}} \doteqdot \delta'\,\frac{1+\dfrac{\omega_x^2}{\omega^2}}{1-\dfrac{\omega\omega_x^2}{\omega^2}} \doteqdot \frac{2\delta'}{1-\omega}$$

δ' refers to the level $r \doteqdot 1-\omega$.

Now expanding (7) and neglecting powers of D greater than the second, we get, as a first approximation,

$$\frac{c^2k_x^2}{p^2}=\frac{1}{2}[D-D^2]=\frac{\delta'}{1-\omega}-\frac{2\delta'^2}{(1-\omega)^2} \quad \ldots \quad \ldots \quad (35)$$

Again for $p<p_h$, we put

$$r \doteqdot 1+\omega$$

so that we get, as before,

$$R \doteqdot 1$$

$$D \doteqdot \frac{2\delta''}{1+\omega}$$

δ'' referring to the level $r \doteqdot 1+\omega$.

Hence, for $p<p_h$, we get,

$$\frac{c^2k^2}{p^2}=\frac{\delta''}{1+\omega}-\frac{2\delta''^2}{(1+\omega)^2} \quad \ldots \quad \ldots \quad \ldots \quad (36)$$

---

* This condition we can take only in the case of long and short waves, where values of θ encountered are small. When we consider medium waves, this condition no longer holds, for θ, for such waves in this case may extend even to 25° as shown in figs. (3) and (4) and we have to use general expressions.

Now for $p > p_h$, we get, from (34) and (35)

$$\frac{k_x^2}{k_o^2} = 2\,\frac{\dfrac{\delta'}{1-\omega} - \dfrac{2\delta'^2}{(1-\omega)^2}}{\delta - \delta^2}$$

$$\doteqdot \frac{2}{1-\omega}\,\frac{\delta'}{\delta} \quad \text{retaining only } \delta \text{ and } \delta'$$

$$\doteqdot \frac{2p}{p-p_h} \quad \text{if we assume that } \delta' \doteqdot \delta$$

$$> 1 \quad \ldots \qquad (37)$$

For $p < p_h$ (34) and (36) yield

$$\frac{k_x^2}{k_o^2} = 2\,\frac{\delta''/(1-\omega) - 2\delta''^2/(1-\omega)^2}{\delta - \delta^2}$$

which after making assumptions similar to the above becomes

$$\frac{k_x^2}{k_o^2} \doteqdot \frac{2p}{p+p_h} < 1 \quad \ldots \qquad (38)$$

Thus in the reflecting region for $p > p_h$ the o-wave is less absorbed than the x-wave, but for $p < p_h$ the reverse happens.

Wells and Berkner (1937) have carried out measurements of the intensities of the o- and the x-waves at Huancayo ($\theta = 2° \; 11'$), a place very near the magnetic equator for a frequency of 4·6 Mc./sec. They find that both the o- and the x-waves are received with almost equal intensities.

Now (38) shows that if the main absorption occurs in the reflecting region $k_x = 1{\cdot}63\ k_o$, while we have shown previously that at such latitudes in the non-reflecting region the two waves will be almost equally absorbed, the ordinary being slightly less absorbed than the extraordinary. This shows that the waves in the above-mentioned experiments suffered absorption mainly in the non-reflecting region.

CASE B.—*Intermediate Magnetic Latitudes.*

For the o-wave we have as before from equation (5)

$$\frac{c^2 k_o^2}{p^2} = \frac{1}{2}[\delta - \delta^2] \quad \ldots \qquad (34)$$

For the x-wave we use equation (13) and substitute

$$r - 1 = -\omega \qquad \text{for } p > p_h$$

$$\text{and} \quad r - 1 = \omega \qquad \text{for } p < p_h$$

After simplification, we get, for $p > p_h$

$$\frac{c^2 k_x^2}{p^2} = \frac{1}{2}\left\{ \frac{(1-|\omega_z|)(|\omega_z| - \omega) - \delta'^2}{(1-|\omega_z|)^2 + \delta'^2} + \sqrt{\frac{(\omega - |\omega_z|)^2 + \delta'^2}{(1-|\omega_z|)^2 + \delta'^2}} \right\} \quad \ldots \qquad (39)$$

Expanding and taking first approximation, we get from (39),

$$\frac{c^2k_x^2}{p^2}=\frac{1}{2}\left\{\frac{|\omega_z|-\omega}{1-|\omega_z|}\left[1-\frac{\delta'^2}{(1-|\omega_z|)(|\omega_z|-\omega)}\right]\left[1-\frac{\delta'^2}{(1-|\omega_z|)^2}\right]\right.$$
$$\left.+\frac{\omega-|\omega_z|}{1-|\omega_z|}\left[1+\frac{1}{2}\frac{\delta'^2}{(\omega-|\omega_z|)^2}\right]\left[1-\frac{1}{2}\frac{\delta'^2}{(1-|\omega_z|)^2}\right]\right\}$$
$$=\frac{1}{4}\frac{\delta'^2(1-\omega)^2}{(1-|\omega_z|)^3(\omega-|\omega_z|)} \quad \ldots \quad \ldots \quad \ldots \quad (40)$$

Similarly for $p<p_h$ we obtain,

$$\frac{c^2k_x^2}{p^2}=\frac{1}{4}\frac{\delta''^2(1+\omega)^2}{(|\omega_z|-1)^3(\omega+|\omega_z|)} \quad \ldots \quad \ldots \quad \ldots \quad (41)$$

Comparing (34) and (40), we get, for $p>p_h$

$$\frac{k_x^2}{k_o^2}=\frac{1}{2}\frac{\delta'^2(1-\omega)^2}{(1-|\omega_z|)^3(\omega-|\omega_z|)(\delta-\delta^2)}$$

which after neglecting δ^2 in comparison to δ and assuming that

$$\delta \doteqdot \delta'$$

becomes

$$\frac{k_x^2}{k_o^2}\doteqdot\frac{1}{2}\frac{\delta(1-\omega)^2}{(1-|\omega_z|)^3(\omega-|\omega_z|)}<1 \quad \ldots \quad \ldots \quad \ldots \quad (42)$$

Similarly, from (34) and (41), we get, for $p<p_h$

$$\frac{k_x^2}{k_o^2}\doteqdot\frac{1}{2}\frac{\delta''^2(1-\omega)^2}{(1+|\omega_z|)^3(\omega+|\omega_z|)(\delta-\delta^2)}$$
$$\doteqdot\frac{1}{2}\frac{\delta''(1-\omega)^2}{(1+|\omega_z|)^3(\omega+|\omega_z|)}<1 \quad \ldots \quad \ldots \quad \ldots \quad (43)$$

From fig. (2) it is clear that for $p=25\times10^6$ we can consider a place for which $\theta=30°$ in this case. For Calcutta where $\theta=31°\,45'$ we have

$$k_x=\cdot7428\times10^{-3}\sqrt{\nu}\,k_o.$$

Even if we assume the value of $\nu=10^6$ for the level from which the x-wave is reflected we have

$$k_x=\cdot7428k_o$$

which shows that the extraordinary wave will be less absorbed than the ordinary wave.

CASE C.—*High Magnetic Latitudes.*

We have already seen that propagation in this region is governed by Case II and we have to use equations (11) and (13) for the o- and the x-wave respectively.

Simplifying (11) as in Case B, we get, for the o-wave

$$\frac{c^2k_o^2}{p^2}=\frac{1}{4}\frac{\delta^2}{\omega_z(1+|\omega_z|)^3} \quad \ldots \quad \ldots \quad \ldots \quad (44)$$

Similarly, from (13) we get for the x-wave for $p>p_h$

$$\frac{c^2k_x^2}{p^2}=\frac{1}{4}\cdot\frac{\delta'^2(1-\omega)^2}{(1-|\omega_z|)^3(\omega-|\omega_z|)} \quad \ldots \quad \ldots \quad \ldots \quad (45)$$

So that for $p>p_h$

$$\frac{k_x^2}{k_o^2}=\frac{|\omega_z|(1-\omega)^2(1+|\omega_z|)^3}{(1-|\omega_z|)^3(\omega-|\omega_z|)}\frac{\delta'^2}{\delta^2}$$

$$\doteq\frac{|\omega_z|(1-\omega)^2(1+|\omega_z|)^3}{(1-|\omega_z|)^3(\omega-|\omega_z|)} \quad \ldots \quad \ldots \quad \ldots \quad (46)$$

$$>1.$$

Again for $p<p_h$ we get for the x-wave, from (13)

$$\frac{c^2k_x^2}{p^2}=\frac{1}{4}\frac{\delta''^2(1+\omega)^2}{(|\omega_z|-1)^3(\omega+|\omega_z|)} \quad \ldots \quad \ldots \quad \ldots \quad (47)$$

so that we get, from (48) and (44), for $p<p_h$

$$\frac{k_x^2}{k_o^2}=\frac{|\omega_z|(1+|\omega_z|)^3(1+\omega)^2}{(|\omega_z|-1)^3(\omega+|\omega_z|)}\frac{\delta''^2}{\delta^2}$$

$$\doteq\frac{|\omega_z|(1+|\omega_z|)^3(1+\omega)^2}{(|\omega_z|-1)^3(\omega+|\omega_z|)} \quad \ldots \quad \ldots \quad \ldots \quad (48)$$

$$>1.$$

(46), (47) and (48) clearly show that in these latitudes the extraordinary wave suffers greater absorption than the o-wave in the reflecting region.

All our results are summarized in the following table :—

Regions	Cases	Sub-cases	Results
Non-Reflecting Region	(a)		$k_o<k_x$, $k_o\doteq k_x$ as we approach the magnetic equator.
	(b)		$k_o<k_x$. But $k_o\doteq k_x$
Reflecting Region	A	$p>p_h$	$k_o<k_x$
		$p<p_h$	$k_o>k_x$
	B	$p>p_h$	$k_o>k_x$
		$p<p_h$	$k_o>k_x$
	C	$p>p_h$	$k_o<k_x$
		$p<p_h$	$k_o<k_x$

We wish to record our hearty thanks to Prof. M. N. Saha, F.R.S., for his constant encouragement and inspiration that he gave us and for many useful discussions and suggestions regarding this paper. We also thank Dr. G. R. Toshniwal for throwing light on certain points. Our thanks are due to Dr. J. N. Bhar for kindly going through the proofs.

REFERENCES.

[1] Appleton (1932). *J.I.E.E.*, **71**, 642.
[2] Appleton (1938). *Proc. Roy. Soc.*, A, **162**, 451.
[3] Appleton and Builder (1933). *Proc. Phys. Soc.*, **45**, 208.
[4] Bhar (1936). *Science and Culture*, **2**, 322.
[5] Booker (1935). *Proc. Roy. Soc.*, A, **150**, 267.
[6] Chapman (1931). *Proc. Phys. Soc.*, **43**, 26.
[7] Forsterling and Lassen (1933). *Ann. d. Phys.*, **18**, 26.
[8] Goubau (1935). *Zs. f. H.F.T.*, **45**, 181.
[9] Hartree (1929). *Proc. Camb. Phil. Soc.*, **25**, 45.
[10] Martyn (1935). *Phil. Mag.*, **19**, 376.
[11] Saha, Rai and Mathur (1938). *Proc. Nat. Inst. Sc. Ind.*, **4**, 353.
[12] Saha and Rai (1938). *Proc. Nat. Inst. Sc. Ind.*, **4**, 319.
[13] Taylor (1934). *Proc. Phys. Soc.*, **46**, 408.
[14] Toshniwal (1936). *Science and Culture*, **2**, 277.
[15] Wells and Berkner (1937). *Terr. Mag.*, **42**, 73.

ABSORPTION AND REFLECTION OF RADIO WAVES AT OBLIQUE INCIDENCE AND THEIR RELATIONSHIP WITH VERTICAL INCIDENCE PHENOMENA.

By K. B. MATHUR, *Physics Department, Allahabad University.*

(Communicated by Prof. M. N. Saha, F.R.S.)

(*Read August 25, 1939.*)

INTRODUCTION.

The success of short wave transmission over long distances is entirely due to the presence of ionized regions in the upper atmosphere, which are responsible for reflecting the signals without much absorption. Greater and greater use is being made of short waves for broadcasting of sound and pictures. For commercial undertakings it is vital to be able to select a frequency which will serve the largest area. Hence the paramount duty of a radio engineer is to find out the most suitable frequency to suit his purpose. However, such a frequency depends entirely upon the conditions existing in the ionosphere which differ from place to place with the season of the year, and hour of the day. Thus we find that the ionospheric data enables the radio engineer to predict the coverage of the projected station, and is thus of the greatest practical importance. It is extremely tedious to collect data for oblique propagation of radio waves, compared to such data for vertical propagation. Much of the radio engineer's work is simplified if he is able to use the vertical incidence results for calculating the absorption and reflection for oblique propagation. Martyn was the first to show that for flat earth it was possible to get oblique incidence data from the data obtained for vertical incidence. Smith (1937) further showed that it was possible to determine graphically the maximum usable frequency for oblique propagation from vertical incidence (virtual height-frequency) curves. Millington (1938) gave a modification for a curved earth of Martyn's theorem and showed that the results hold for both equivalent frequency and absorption for a thin layer. Smith (1938) has further extended the work and has removed the restriction of the thin layer. He has deduced the relation only for equivalent frequency assuming linear distribution of electrons but has neglected absorption.

In the present paper, relations have been deduced for absorption as well as for equivalent frequency for the linear and also for the exponential gradient of ionization in a thick layer. The earth's magnetic field has been neglected, and the gradient of electron density has been taken to be everywhere vertical and similar throughout.

1. Absorption.

Fig. 1 shows the transmitter T and the receiver R, separated by a distance D. The sky wave leaves the ground at an angle α and enters the ionosphere at A, ϕ_1 being the angle of incidence.

ϕ = the angle the wave normal makes with the vertical at the altitude z above A.

h = height of the ionosphere.

R = radius of the earth.

z_0 = the maximum height of penetration above the lower boundary of the ionosphere.

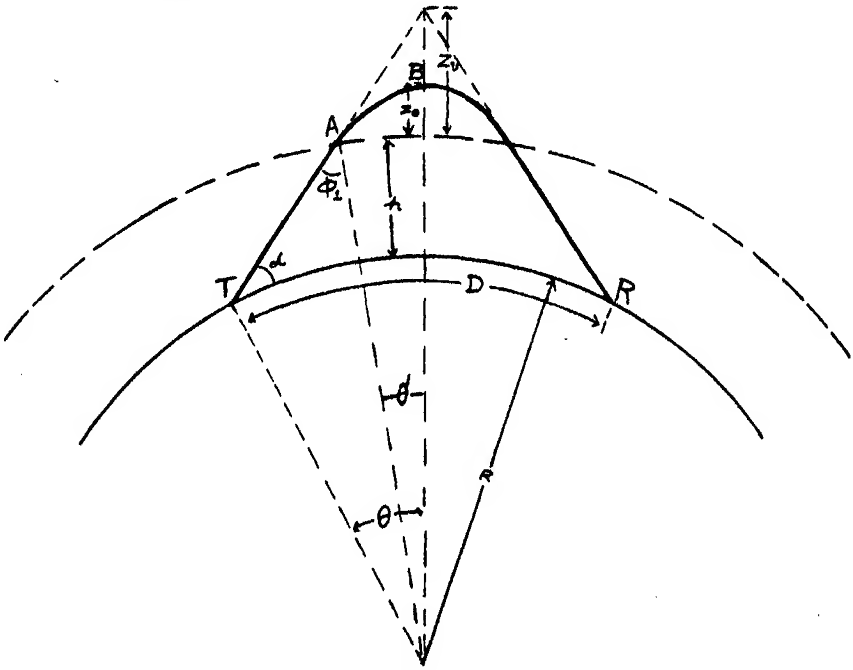


Fig. 1.

z_v = the height of the equivalent triangle above the lower boundary.

ϕ_0 = half the angle at the vertex of the equivalent triangle.

z'_v = the vertical height measured at vertical incidence.

f' = actual wave frequency at oblique propagation.

f = the equivalent frequency of f' reflected at vertical incidence from the same height z.

$f_0 = \sqrt{\dfrac{Ne^2}{m\pi}}$.

N = number of electrons per c.c.

e = charge of an electron.

m = mass of an electron.

μ_0' = the value of the refractive index μ' where the reflection takes place.

t = time taken by the sky wave to travel from T to R.

In order to avoid repetition the following equations—which have been used in the present calculations—are reproduced from Smith's paper (1938).

$$\sqrt{1-\mu_0'^2} = \cos\phi_1 \sqrt{1+\frac{2z_0}{R+h}\tan^2\phi_1} \quad \ldots \quad (1)$$

$$= \cos\phi_0 \sqrt{1-\frac{2(z_v-z_0)}{R+h}\tan^2\phi_0} \quad \ldots \quad (1a)$$

$$f = f'\sqrt{1-\mu_0'^2} = f'\cos\phi_1 \sqrt{1+\frac{2z_0}{R+h}\tan^2\phi_1} \quad \ldots \quad (2)$$

$$\theta' = \frac{\sin\phi_1}{(R+h)\sqrt{1-\mu_0'^2}} \int_0^{z_0} \frac{dz}{\sqrt{1-f_0^2/f^2}}(1+B)\left(1-\frac{2z}{R+h}\right) \quad \ldots \quad (3)$$

where
$$1+B = \frac{1}{\sqrt{1-A\left(\dfrac{f^2}{f^2-f_0^2}\right)}} \quad \ldots \quad (3a)$$

and
$$1-A = \frac{1-\dfrac{\sin^2\phi_1}{\left(1+\dfrac{z}{R+h}\right)^2}}{1-\mu_0'^2} = \frac{1+\dfrac{2z}{R+h}\tan^2\phi_1}{1+\dfrac{2z_0}{R+h}\tan^2\phi_1} \quad \ldots \quad (3b)$$

$$\theta-\theta' = \cot\phi_1 - \sqrt{\cot^2\phi_1-\frac{2h}{R}} \quad \ldots \quad (4)$$

$$D = 2R\theta \quad \ldots \quad (5)$$

$$z_v = (R+h)[\sin\theta'\cot(\theta-\theta')-1+\cos\theta'] \quad \ldots \quad (6)$$

$$z_v' = \int_0^{z_0} \frac{dz}{\sqrt{1-f_0^2/f^2}} \quad \ldots \quad (7)$$

$$\int_A^B \frac{ds}{\mu} = \int_0^{z_0} \frac{f\,dz}{\sqrt{1-\mu_0'^2}\sqrt{f^2(1-A)-f_0^2}} = \int_0^{z_0} \frac{f'\,dz}{\sqrt{f'\left\{1-\dfrac{\sin^2\phi_1}{\left(1-\dfrac{z}{R+h}\right)^2}\right\}-f_0^2}} \quad (8)$$

$$t = \frac{2}{c}\left[\frac{R\sin(\theta-\theta')}{\sin\phi_1}+\int_A^B\frac{ds}{\mu}\right] \quad \ldots \quad (9)$$

$$=\frac{2}{c}\left[\frac{R\sin(\theta-\theta')}{\sin\phi_1}+\frac{1}{\sqrt{1-\mu_0'^2}}\int_0^{z_0}\frac{f\,dz}{\sqrt{f^2(1-A)-f_0^2}}\right] \quad \ldots \quad (9a)$$

$$=\frac{2}{c}\left[\frac{R\sin(\theta-\theta')}{\sin\phi_1}+\frac{f'}{f}\int_0^{z_0}\frac{dz}{\sqrt{1-f_0^2/f^2}}(1+B)\right] \quad \ldots \quad \ldots \quad (9b)$$

where θ is half the angle the total ray path subtends at the centre of the earth, while θ' is half the angle subtended at the earth's centre by the ray path inside the ionosphere.

The absorption coefficient per unit path of the ray is given by

$$k=\frac{\nu}{2c\mu}\,\frac{f_0^2}{f^2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

where the collisional frequency of the electrons, ν, is a function of z.

Using equations (2), (3a) and (8), the total absorption for oblique propagation is

$$\int_{\text{ob.}} k\,ds = 2\int_0^{z_0}\frac{\nu}{2c}\,\frac{f_0^2}{f'^2}\,\frac{f'\,dz}{\sqrt{f'^2\left\{1-\dfrac{\sin^2\phi_1}{\left(1-\dfrac{z}{R+h}\right)^2}\right\}-f_0^2}} \quad \ldots \quad (11)$$

$$=\int_0^{z_0}\frac{\nu}{c}\,\frac{f_0^2}{f}\,\frac{\sqrt{1-\mu_0'^2}\,dz}{\sqrt{\dfrac{f^2}{1-\mu_0'^2}\left\{1-\dfrac{\sin^2\phi_1}{\left(1-\dfrac{z}{R+h}\right)^2}\right\}-f_0^2}} \quad \ldots \quad (11a)$$

$$=\frac{\cos\phi_1\sqrt{1+\dfrac{2z_0\tan^2\phi_1}{R+h}}}{cf^2}\int_0^{z_0}\frac{\nu f_0^2(1+B)dz}{\sqrt{1-f_0^2/f^2}} \quad \ldots \quad (11b)$$

This relation is similar to that obtained by Millington (1938) who has, however, studied the case of a thin layer, and finds that even for absorption Martyn's theorem holds.

For vertical incidence $\phi_1=0$, and $\displaystyle\int_{\text{ve.}} k\,ds=\frac{1}{cf^2}\int_0^{z_0}\frac{\nu f_0^2\,dz}{\sqrt{1-f_0^2/f^2}}$ (12)

The total absorption for oblique propagation can be easily found for special cases; viz:—

(a) $z_0 << \frac{1}{2}(R+h)\cot^2\phi_1$.

This case applies to E-layer transmission for any distance and to F-layer transmission for short distances. In this case (3*a*) and (3*b*) reduce to (as proved by Smith)

$$1-A = 1+\frac{2(z-z_0)\tan^2\phi_1}{R+h} \quad \ldots \quad \ldots \quad \ldots \quad (13)$$

$$1+B = 1+\frac{z_0\tan^2\phi_1}{R+h}\,\frac{1-z/z_0}{1-f_0^2/f^2} \quad \ldots \quad \ldots \quad (14)$$

Hence

$$\int_{\text{ob.}} kds = \frac{\cos\phi_1\left(1+\dfrac{z_0\tan^2\phi_1}{R+h}\right)}{cf^2}\times\int_0^{z_0}\frac{\nu f^2}{\sqrt{1-\dfrac{f_0^2}{f^2}}}\left\{1+\frac{z_0\tan^2\phi_1}{R+h}\,\frac{1-\dfrac{z}{z_0}}{1-\dfrac{f_0^2}{f^2}}\right\}dz \quad (15)$$

Case I.—Linear distribution of ionic-density.

$$1-z/z_0 = 1-f_0^2/f^2$$

and hence,

$$\int_{\text{ob.}} kds = \frac{\cos\phi_1\left(1+\dfrac{z_0}{R+h}\tan^2\phi_1\right)^2}{cf^2}\int_0^{z_0}\frac{\nu f_0^2\,dz}{\sqrt{1-f_0^2/f^2}}$$

Using (12)

$$\int_{\text{ob.}} kds = \cos\phi_1\left(1+\frac{2z_0\tan^2\phi_1}{cf^2}\right)\int_{\text{ve.}} kds \quad \ldots \quad \ldots \quad (16)$$

but from (7)

$$z_v' = 2z_0$$

hence,

$$\int_{\text{ob.}} kds = \cos\phi_1\left(1+\frac{z_v'\tan^2\phi_1}{R+h}\right)\int_{\text{ve.}} kds. \quad \ldots \quad \ldots \quad (16a)$$

Case II.—Exponential distribution of ionic density.

$$f_0^2 = \gamma^2 e^{\beta z},\ f^2 = \gamma^2 e^{\beta z_0} \text{ and } \nu = \nu_1 e^{-\frac{z}{H}} \quad \ldots \quad \ldots \quad (16b)$$

where H is the height of the homogeneous atmosphere. By substituting these in equation (22), we get

$$\int_{\text{ve.}} kds = \frac{1}{cf^2}\int_0^{z_0}\frac{\nu_1\gamma^2 e^{-\frac{z}{H}}e^{\beta z}\,dz}{\sqrt{1-e^{\beta(z-z_0)}}}$$

Putting

$$e^{\beta(z-z_0)} = \cos^2\theta$$

$$\int_{\text{ve.}} kds = \frac{2\nu_1\gamma^2 e^{z_0\left(\beta-\frac{1}{H}\right)}}{\beta c f^2} \int_0^{\cos^{-1}\left(e^{-\beta z_0/2}\right)} (\cos\theta)^{\left(1-\frac{2}{\beta H}\right)} d\theta \quad \ldots \quad (17)$$

When $\dfrac{2}{\beta H} << 1$, $$\int_{\text{ve.}} kds = \frac{2\nu_1\gamma^2 e^{z_0\left(\beta-\frac{1}{H}\right)}}{\beta c f^2}\sqrt{1-e^{-\beta z_0}} \quad \ldots \quad \ldots \quad (18)$$

Now for oblique propagation eqn. (15) gives

$$\int_{\text{ob.}} kds = \frac{\cos\phi_1\left(1+\dfrac{z_0\tan^2\phi_1}{R+h}\right)}{cf^2}\int_0^{z_0} \frac{\nu_1\gamma^2 e^{-\frac{z}{H}} e^{\beta z}}{\sqrt{1-e^{\beta(z-z_0)}}} \times \left\{1-\frac{\tan^2\phi_1}{R+h}\,\frac{z-z_0}{1-e^{\beta(z-z_0)}}\right\} dz \quad (19)$$

Putting

$$e^{\beta(z-z_0)} = \cos^2\theta$$

$$\int_{\text{ob.}} kds = \frac{\cos\phi_1\left(1+\dfrac{z_0\tan^2\phi_1}{R+h}\right)}{cf^2}\int_0^{\cos^{-1}\left(e^{-\frac{\beta z_0}{2}}\right)} \frac{2\nu_1\gamma^2 e^{z_0\left(\beta-\frac{1}{H}\right)}}{\beta}(\cos\theta)^{1-\frac{2}{\beta H}}$$

$$\times\left\{1-\frac{2}{\beta}\,\frac{\tan^2\phi_1}{(R+h)}\,\frac{\log\cos\theta}{\sin^2\theta}\right\} d\theta.$$

When $$\frac{2}{\beta H} << 1$$

$$\int_{\text{ob.}} kds = \cos\phi_1\left(1+\frac{z_0}{R+h}\tan^2\phi_1\right)\left[\int_{\text{ve.}} kds\right.$$

$$\left.+\frac{2}{\beta}\,\frac{\tan^2\phi_1}{R+h}\,\frac{\nu_1\gamma^2 e^{z_0\left(\beta-\frac{1}{H}\right)}}{cf^2}\left(z_v'-\frac{z_0}{\sqrt{1-e^{-\beta z_0}}}\right)\right]$$

$$= \cos\phi_1\left[1+\frac{\tan^2\phi_1}{R+h}\left\{\frac{z_v'}{\sqrt{1-e^{-\beta z_0}}}+z_0\left(1-\frac{1}{1-e^{-\beta z_0}}\right)\right\}\right]\int_{\text{ve.}} kds$$

$$= \cos\phi_1\left[1+\frac{z_v'\tan^2\phi_1}{R+h}\right]\int_{\text{ve.}} kds \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (20)$$

where z_v' is given by the eqn. (32), proved later on. Thus we find that the absorptions for linear and exponential distribution of electrons come out to be the same.

(*b*) Thin layer; $z_0 \to 0$.

Case I.—Linear distribution.

$$\int_{\text{ob.}} kds = \cos\phi_1 \int_{\text{ve.}} kds \qquad \ldots \quad \ldots \quad \ldots \quad (21)$$

as deduced by Millington, as well as Martyn.

Case II.—Exponential gradient of ionic density.

Eqn. (20) reduces to

$$\int_{\text{ob.}} kds = \cos\phi_1 \left[\int_{\text{ve.}} kds + \frac{2}{\beta}\frac{\tan^2\phi_1 \nu_1 \gamma^2}{(R+h)}\frac{z_v'}{cf^2} \right] \qquad \ldots \quad (22)$$

(*c*) For $z_0 \to z_v'$.

We find that the ray suffers hardly any deviation till the point of reflection is reached. The sporadic E-region can be cited as an excellent example of such reflections.

From (1*a*), we have

$$\sqrt{1-\mu_0'^2} = \cos\phi_0 \left(1 - \frac{z_v' - z_0}{R+h}\tan^2\phi_0\right)$$

For $z_v' - z_0$ vanishingly small compared with $(R+h)\cot^2\phi_0$ this reduces to

$$\sqrt{1-\mu_0'^2} = \cos\phi_0 = f/f' \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (23)$$

and we have from (11*a*) by substituting from (23)

$$\int_{\text{ob.}} kds = \int_0^{z_0} \frac{\cos\phi_0}{cf} \frac{\nu f_0^2\, dz}{\sqrt{f^2 \dfrac{\cos^2\phi_1}{\cos^2\phi_0}\left(1+\dfrac{2z\tan^2\phi_1}{R+h}\right) - f_0^2}} \qquad \ldots \quad (24)$$

Case I.—Linear distribution of ionic density.

Put

$$f_0^2 = \gamma_1^2 z, \quad f^2 = \gamma_1^2 z_0 \quad \text{and} \quad \nu = \nu_1 e^{-\frac{z}{H}}$$

We have from (24)

$$\int_{\text{ob.}} kds = \int_0^{z_0} \frac{\cos^2\phi_0}{\cos^2\phi_1}\frac{\nu_1\gamma_1}{cf} \frac{ze^{-\frac{z}{H}}\, dz}{\sqrt{z_0 - z\left(\dfrac{\cos^2\phi_0}{\cos^2\phi_1} - \dfrac{2z_0\tan^2\phi_1}{R+h}\right)}} \qquad \ldots \quad (25)$$

Putting

$$z\left(\frac{\cos^2\phi_0}{\cos^2\phi_1}-\frac{2z_0\tan^2\phi_1}{R+h}\right)=za^2=z_0\cos^2\theta$$

$$\int_{\text{ob.}} kds=\frac{2\cos^2\phi_0\nu_1\gamma_1 z_0^{\frac{3}{2}}}{\cos\phi_1 cf^2a^4}\int_{\cos^{-1}a}^{\frac{\pi}{2}} e^{-\frac{z_0\cos^2\theta}{a^2H}}\cos^3\theta\, d\theta$$

$$=\frac{2\cos^2\phi_0\nu_1\gamma_1 z_0^{\frac{3}{2}}e^{-\frac{z_0}{2a^2H}}}{\cos\phi_1 cf^2a^4}\int_{\cos^{-1}a}^{\frac{\pi}{2}} e^{-\frac{z_0\cos 2\theta}{2a^2H}}\cos^3\theta\, d\theta \quad .. \quad (26)$$

The first term in the above integral can be expanded by Sonine's Theorem

$$e^{A\cos\psi}=I_0(A)+2\sum_{n=1}^{n=\infty}I_n(A)\cos n\psi$$

where $I_n(A)$ is the modified Bessel Coefficient given by

$$I_n(A)=\sum_{k=0}^{\infty}\frac{1}{\pi(k)\pi(n+k)}\left(\frac{A}{2}\right)^{n+2k}$$

and $\pi(k)$ is Gauss's function having the values unity for $k=0$ and $\lfloor k$ for positive integral values of k.

The integral in eqn. (26) can be approximately solved by taking the first few terms of the expansion. The expression for the total absorption for oblique propagation is given by

$$\int_{\text{ob.}} kds=\frac{2\cos^2\phi_0\nu_1\gamma_1}{\cos\phi_1 cf^2}\,\frac{z_0^{\frac{3}{2}}}{a^4}\,e^{-\frac{z_0}{2a^2H}}\Bigg[\left\{\frac{2}{3}-\frac{\sqrt{1-a^2}}{3}(a^2+2)\right\}$$

$$-\left(\frac{z_0}{4a^2H}\right)\left\{\frac{4}{5}-\sqrt{1-a^2}\left(\frac{2}{5}a^3+\frac{4}{5}a^2+\frac{4}{5}\right)\right\}$$

$$+\left(\frac{z_0}{4a^2H}\right)^2\left\{\frac{76}{105}-\sqrt{1-a^2}\left(\frac{8}{7}a^6-\frac{3}{35}a^4+\frac{38}{105}a^2+\frac{76}{105}\right)\right\}$$

$$-\left(\frac{z_0}{4a^2H}\right)^3\left\{\frac{376}{945}-\sqrt{1-a^2}\left(\frac{32}{27}a^8-\frac{176}{189}a^6+\frac{94}{315}a^4+\frac{164}{945}a^2+\frac{376}{945}\right)\right\}\Bigg] \quad (27)$$

where $$a^2=\frac{\cos^2\phi_0}{\cos^2\phi_1}-\frac{2z_0\tan^2\phi_1}{R+h}$$

For vertical propagation $\phi_1=\phi_0=0$, hence $a=1$. If we put these values in eqn. (27) we get the same expression as obtained by Martyn (1935).

The exponential gradient of ionization has not been used for calculating the total absorption in this case ($z_0 \to z_B$) since the deviating region is too thin.

2. Relation for Equivalent Frequency.

To find out relations for maximum usable frequency with distance we have to simplify eqns. (1) to (9), but then we must know the law of distribution of electron-density. Smith (1938) has assumed this as linear and obtained simplified forms of equations (3), (7), (8) and (9). However, the actual conditions in the ionosphere are well explained by assuming exponential gradient of ionization. In what follows the particular cases are discussed and results derived assuming that the number of electrons per unit volume $N \propto e^{\beta z}$

(a) $z_o << \frac{1}{2}(R+h)\cot^2\phi_1$.

In this case eqn. (1) reduces to

$$f = f' \cos\phi_1\left(1+\frac{z_o\tan^2\phi_1}{R+h}\right) \quad \ldots \quad \ldots \quad \ldots \quad (28)$$

and eqn. (3) becomes

$$\theta' = \frac{\tan\phi_1}{R+h}\left(1-\frac{z_o\tan^2\phi_1}{R+h}\right)\int_0^{z_0}\frac{dz}{\sqrt{1-f_0^2/f^2}}\left\{1+\frac{z_o\tan^2\phi_1}{R+h}\;\frac{1-z/z_o}{1-f_0^2/f^2}-\frac{2z}{R+h}\right\} \quad (29)$$

Now for exponential gradient of ionization, let us put

$$f_o^2 = \gamma^2 e^{\beta z} \text{ and } f^2 = \gamma^2 e^{\beta z_0} \quad \ldots \quad \ldots \quad \ldots \quad (30)$$

and obtain the forms of various equations. From (29), (30) we have

$$\theta' = \frac{\tan\phi_1}{R+h}\left(1-\frac{z_o\tan^2\phi_1}{R+h}\right)\int_0^{z_0}\frac{dz}{\sqrt{1-e^{\beta(z-z_0)}}}\left\{1-\frac{\tan^2\phi_1}{R+h}\;\frac{z-z_o}{1-e^{\beta(z-z_0)}}-\frac{2z}{R+h}\right\} (31)$$

and (7) reduces to

$$z_v' = \int_0^{z_0}\frac{dz}{\sqrt{1-e^{\beta(z-z_0)}}}$$

$$= \frac{2}{\beta}\log\frac{1+\sqrt{1-e^{-\beta z_0}}}{e^{-\beta z_0/2}} \quad \ldots \quad \ldots \quad \ldots \quad (32)$$

$$= \frac{2}{\beta}\log 2 + z_o \qquad \text{since } e^{-\beta z_0} << 1 \quad \ldots \quad (32a)$$

(31) can also be put as

$$\theta' = \frac{\tan\phi_1}{R+h}\left[1-\frac{z_o\tan^2\phi_1}{R+h}\right]\left[z'_v-\frac{\tan^2\phi_1}{R+h}C_1-\frac{2}{R+h}C_2\right] \quad \ldots \quad (33)$$

where

$$C_1 = \int_0^{z_0} \frac{z - z_o}{(1 - e^{\beta(z - z_0)})^{\frac{3}{2}}}\, dz$$

$$= \frac{2z_0}{\beta\sqrt{1 - e^{-\beta z_0}}} - \frac{2}{\beta} z_v' + \frac{4}{\beta^2} \int_0^{\cos^{-1}\left(e^{-\frac{\beta z_0}{2}}\right)} \frac{\log(\cos\theta)}{\cos\theta}\, d\theta$$

$$C_2 = \int_0^{z_0} \frac{z\, dz}{\sqrt{1 - e^{\beta(z - z_0)}}} = z'_v z_o + \frac{4}{\beta^2} \int_0^{\cos^{-1}\left(e^{-\frac{\beta z_0}{2}}\right)} \frac{\log(\cos\theta)}{\cos\theta}\, d\theta.$$

Now $$\int_0^{\cos^{-1}\left(e^{-\frac{\beta z_0}{2}}\right)} \frac{\log(\cos\theta)}{\cos\theta}\, d\theta = -\int_0^{\frac{\beta z_0}{2}} \psi(1 - e^{-2\psi})^{-1/2}\, d\psi.$$

Expanding and performing the integration we have to a close approximation,

$$-\int_0^{\cos^{-1}\left(e^{-\frac{\beta z_0}{2}}\right)} \frac{\log(\cos\theta)}{\cos\theta}\, d\theta$$

$$= \frac{1}{2}\left(\frac{\beta z_o}{2}\right)^2 - \frac{e^{-\beta z_0}}{8}(\beta z_o + 1) - \frac{3}{64} e^{-2\beta z_0}\left(\beta z_o + \frac{1}{2}\right) - \frac{5}{192} e^{-3\beta z_0}\left(\beta z_o + \frac{1}{3}\right) - \frac{181}{1152} \quad (34)$$

Hence,

$$\theta' = \frac{\tan\phi_1}{R+h}\left(1 - \frac{z_o \tan^2\phi_1}{R+h}\right)\Bigg[z'_v - \frac{\tan^2\phi_1}{R+h}\left(\frac{2z_0}{\beta(1 - e^{-\beta z_0})^{1/2}} - \frac{2}{\beta} z'_v\right)$$

$$- \frac{2z_o z'_v}{R+h} - \left(\frac{4}{\beta^2}\frac{\tan^2\phi_1}{R+h} + \frac{4}{\beta^2}\frac{z}{R+h}\right) \int_0^{\cos^{-1}\left(e^{-\frac{\beta z_0}{2}}\right)} \frac{\log(\cos\theta)}{\cos\theta}\, d\theta\Bigg]$$

$$= \frac{\tan\phi_1}{R+h}\left(1 - \frac{z_o\tan^2\phi_1}{R+h}\right)\Bigg[z'_v\left(1 - \frac{2z_o}{R+h}\right) - \frac{2}{\beta}\frac{\tan^2\phi_1}{R+h}\left(\frac{z_o}{(1 - e^{-\beta z_0})^{1/2}} - z'_v\right)$$

$$+ \frac{4}{\beta^2}\frac{(\tan^2\phi_1 + 2)}{R+h}\Bigg\{\frac{\beta^2 z_o^2}{8} - \frac{e^{-\beta z_0}}{8}(\beta z_o + 1) + \frac{3}{64} e^{-2\beta z_0}\left(\beta z_o + \frac{1}{2}\right)$$

$$- \frac{5}{192} e^{-3\beta z_0}\left(\beta z_o + \frac{1}{3}\right) - \frac{181}{1152}\Bigg\}\Bigg] \quad \ldots \quad \ldots \quad \mathbf{(35)}$$

Now $e^{-\beta z_0} << 1$, neglecting coefficients of $e^{-\beta z_0}$, and using (32a), θ' can be written in a more modified form as,

$$\theta' = \frac{\tan\phi_1}{R+h}\left[z'_v\left\{1+\frac{z'_v}{R+h}\left(\frac{\tan^2\phi_1}{2}-1\right)+\frac{2\tan^2\phi_1}{R+h}(1-\log 2)\right\}\right.$$
$$\left.+\frac{4}{\beta^2}\frac{\log 2}{R+h}\left\{\log 2\left(1+\frac{1}{2}\tan^2\phi_1\right)+\tan^2\phi_1\right\}\right]$$

and to a further approximation

$$\theta' = \frac{\tan\phi_1}{R+h}\left[z'_v\left\{1-\frac{z'_v}{R+h}\left(1-\frac{\tan^2\phi_1}{2}\right)\right\}\right] \quad \ldots \quad \ldots \quad (36)$$

Using eqns. (13), (14), (16a) and (28), (9b) becomes

$$t = \frac{2}{c}\left[\frac{R\sin(\theta-\theta')}{\sin\phi_1}+\frac{\left(1-\frac{z_o\tan^2\phi_1}{R+h}\right)}{\cos\phi_1}\int_0^{z_0}\frac{dz}{\sqrt{1-\frac{f_o^2}{f^2}}}\right.$$
$$\left.\left\{1-\frac{z_o\tan^2\phi_1}{R+h}\left(1-\frac{1-\frac{z}{z_o}}{1-\frac{f_o^2}{f^2}}\right)\right\}\right]$$

$$= \frac{2}{c}\left[\frac{R\sin(\theta-\theta')}{\sin\phi_1}+\frac{\left(1-\frac{z_o\tan^2\phi_1}{R+h}\right)}{\cos\phi_1}\int_0^{z_0}\frac{dz}{\sqrt{1-e^{\beta(z-z_0)}}}\right.$$
$$\left.\left\{1-\frac{z_o\tan^2\phi_1}{R+h}\frac{\tan^2\phi_1}{R+h}\frac{z-z_o}{1-e^{\beta(z-z_0)}}\right\}\right]$$

$$= \frac{2}{c}\left[\frac{R\sin(\theta-\theta')}{\sin\phi_1}+\frac{\left(1-\frac{z_o\tan^2\phi_1}{R+h}\right)}{\cos\phi_1}\left\{z'_v\left(1-\frac{z_o\tan^2\phi_1}{R+h}\right)\right.\right.$$
$$-\frac{\tan^2\phi_1}{R+h}\frac{2}{\beta}\left(\frac{z_0}{\sqrt{1-e^{-\beta z_0}}}-z'_v\right)+\frac{\tan^2\phi_1}{R+h}\frac{4}{\beta^2}\left(\frac{\beta^2 z_o^2}{8}-\frac{e^{-\beta z_0}}{8}(\beta z_o+1)\right.$$
$$\left.\left.\left.-\frac{3}{64}e^{-2\beta z_0}\left(\beta z_o+\frac{1}{2}\right)-\frac{5}{192}e^{-3\beta z_0}\left(\beta z_o+\frac{1}{3}\right)-\frac{181}{1152}\right)\right\}\right] \quad \ldots \quad (37)$$

Making similar simplification as has been done for θ' and using (32a) t can be written in a modified form as

$$t = \frac{2}{c}\left[\frac{R\sin(\theta-\theta')}{\sin\phi_1}+\frac{1}{\cos\phi_1}\left\{z'_v\left(1-\frac{3}{2}\frac{\tan^2\phi_1}{R+h}z'_v+\frac{2}{\beta}\frac{\tan^2\phi_1}{R+h}\log 2\right)\right.\right.$$
$$\left.\left.+\frac{2}{\beta^2}\frac{\tan^2\phi_1}{R+h}\log 2\,(2+\log 2)\right\}\right] \quad \ldots \quad \ldots \quad (38)$$

and to a further approximation

$$t = \frac{2}{c}\left[\frac{R \sin(\theta-\theta')}{\sin \phi_1} + \frac{z_v'}{\cos \phi_1}\left(1 - \frac{3}{2}\frac{\tan^2 \phi_1}{R+h} z_v'\right)\right] \quad \ldots \quad (39)$$

Relations (4), (5) and (6) will remain the same as deduced by Smith.

3. Conclusion and Discussion.

It is now well known that the intensity of the sky-wave increases for all frequencies up to a distance of about 500 kms. after which it slowly decreases—*vide* Report of committee on radio wave propagation, *P.I.R.E.* Vol. 26, p. 1193, (1938). The theory of absorption worked out by Martyn for flat earth and Millington for curved earth for thin layer both lead to the same results, *i.e.*, the absorption for oblique propagation is sec ϕ_1 times the absorption for vertical propagation. This theory is unable to explain the maximum in the signal strength observed experimentally. However, as has been done in this paper, if the absorption is calculated for a thick layer we see from eqn. (20) that it decreases upto a certain distance, after which it increases, which can explain the form of the signal intensity curve obtained experimentally. It may be pointed out that the exact distance from the transmitter where the maximum of signal intensity is observed cannot be calculated from these results, since we have assumed the condition $z_0 << \frac{1}{3}(R+h) \cot^2 \phi_1$. The removal of this restriction probably enables us to calculate the exact place where the maximum of signal intensity is observed. But the calculations are too tedious, and will be dealt with later. It should be noted that our results show that the absorption for both the linear and exponential distribution of electrons comes out to be the same.

In § 2 the various relations have been deduced on the hypothesis of exponential distribution of electrons in the ionosphere. The equations for θ' and t presented in this paper are slightly different from those given by Smith (1938) for linear distribution. The value of θ' obtained for exponential distribution is smaller than that obtained for linear distribution as long as $\tan^2 \phi_1 \leq \frac{2}{3}$, *i.e.*, $\phi_1 \leq 39° \ 16'$, while for values of ϕ_1 greater than 39° 16′, the reverse will happen. The time taken by the ray to reach the receiver, t, depends upon two factors, viz. (1) $\dfrac{R \sin(\theta-\theta')}{\sin \phi_1}$ and (2) $\displaystyle\int_0^{z_0} \frac{ds}{\mu}$. The value of $\dfrac{R \sin(\theta-\theta')}{\sin \phi_1}$ depends upon θ', the variation of which has already been discussed. $\displaystyle\int_0^{z_0} \frac{ds}{\mu}$ will always be less for exponential distribution than for linear distribution as is evident from eqn. (39) and the one deduced by Smith (1938) on page 696, case (*b*). (There appears to be a slip in his formula for T. It should

be $T = \frac{2}{c}\left\{\frac{R \sin(\theta-\theta')}{\sin\phi_1}+\frac{z'_v}{\cos\phi_1}\right\}$). Hence for long distances the time taken by the sky-wave is smaller for exponential distribution than the time taken if the electrons are distributed linearly. The exponential distribution of electrons represents the conditions existing in the ionosphere in a better way, therefore curves plotted after Smith (1938) using the results presented here will, it is hoped, give a more accurate value for maximum usable frequency.

My best thanks are due to Prof. M. N. Saha, F.R.S., and Dr. G. R. Toshniwal, D.Sc., for their keen interest and useful suggestions.

REFERENCES.

Martyn, D. F. (1935). *Proc. Phys. Soc.*, 47, 332.
Millington, G. (1938). *Proc. Phys. Soc.*, 50, 801.
Smith, N. (July, 1937). *Bur. Stand. J. Res.*, 19.
Smith, N. (May, 1938). *Bur. Stand. J. Res.*, 20.

ABSTRACT.

It is extremely useful to obtain data for long-distance transmission of electromagnetic waves through the ionosphere from observations made at vertical incidence. Martyn first showed that the absorption for oblique propagation is simply related to that observed at vertical incidence with the three simplifying assumptions: (i) that the gradient of electron density is everywhere vertical and similar throughout the path of the ray, (ii) that the earth's magnetic field can be neglected and (iii) that the earth is flat. Smith further showed that the maximum usable frequency for oblique propagation could also be derived from the characteristics of $(P'-f)$ curves obtained at vertical incidence under the same assumptions as those of Martyn. Millington developed the above theorems for a curved earth and showed them to hold for a relatively thin layer. Millington's work has been further modified by Smith to allow for a thick layer assuming linear distribution of electron density. But he has only derived an expression for equivalent frequency. In the present paper, starting from Smith's theorems, relations have been deduced both for equivalent frequency as well as for absorption for the cases of linear and exponential gradient of electron density.

AN ATTEMPT TO NEUTRALIZE THE SPACE-CHARGE OF A HOT FILAMENT BY FAST POSITIVE IONS OF MERCURY. PART I.

By R. M. Chaudhri, *M.Sc., Ph.D.* (*Cantab*), S. M. Nawaz, *M.Sc., and* M. Aslam, *M.Sc., Department of Physics, Muslim University, Aligarh.*

(Communicated by the Hon'ble Sir S. M. Sulaiman.)

(*Received November 3, 1939.*)

Introduction.

A metallic surface when sufficiently hot emits thermionic electrons and the thermionic current at any temperature θ is given by the relation

$$i = a\theta^{1/2} e^{-b/\theta}$$

where 'a' and 'b' are constants depending upon the material of the surface and the nature and pressure of the vapours surrounding it (Richardson, 1902). If a plate is placed at a few mms. away from the surface and is charged positively with respect to it, the plate current is saturated at low temperatures and does not vary much with plate potentials. At higher temperatures, however, the plate current is independent of temperatures but varies with the potential difference between the plate and the hot surface (Langmuir, 1913). This is due to the presence of a negative space-charge near the surface which acts as a barrier to the flow of electrons from the filament to the plate and thus limits the electron current. If by some means the space-charge or its effect is neutralized the flow of electrons to the plate will be facilitated and the plate current would show an increase. Hertz (1923) has developed a method for the determination of ionization potentials of Neon and Argon, in which the effect of the space-charge round a hot filament is neutralized by the ions of low velocities. The positive ions were produced by the ionization of these gases caused by a beam of electrons coming from a separate filament.

In the present experiment an attempt has been made to reduce the space-charge by fast Mercury positive ions obtained from an independent source.

Description of the Apparatus.

The Mercury ions were produced from a hot cathode Mercury Arc shown in Fig. 1.

F_1 is a filament, in the form of a narrow spiral, of a few turns of Tungsten wire of 0·2 mm. diameter, and is surrounded by a metallic spiral S. A reservoir of pure mercury is connected to the pyrex bulb B to maintain a supply of Mercury vapours. The filament is heated by an A.C. current obtained from an insulated secondary of a transformer and controlled by a resistance in the

primary. The Mercury Arc was set up by applying a potential of 100–150 volts D.C. between F_1 and S. The Hg Arc could give current up to 300 milliamperes.

A Langmuir probe, L, in the form of a circular disc, 2 cms. in diameter and having a circular hole of 4 mms. diameter at the centre, is fixed to one side of the bulb B. A hollow metallic canal C, 5 cms. long and 4 mms. in diameter, is spot-welded to the back of the probe with its axis perpendicular to the plane of the disc and passing through its centre. The probe is held firm in position by sealing the canal into the pyrex bulb at O.

The Mercury positive ions are sucked from the Mercury Arc by applying a negative potential on L. The ions are accelerated through C and pass into the chamber K. The spread of the ions is checked by a slit S_1. F_2 is another filament of thin Tungsten wire, which is also heated by an A.C. current from an insulated secondary of a transformer and controlled as in the previous case. The plate P, about four square cms. in area, is placed a few mms. above F_2, and is charged positively with respect to it to collect electrons from F_2. A long hollow Faraday cylinder, A, collects the positive ions at the end of the beam. The geometry of the cylinder is such that the secondary electrons (Oliphant, 1928; Jackson, 1927) emitted from its inner surface by the incoming ions are entrapped within and thus do not produce any disturbance in the plate current or the space-charge of the hot surface.

All-metal joints were made by spot-welding the different parts together and were fixed in position in the pyrex glass apparatus with pyrex Tungsten seals. The whole apparatus is of pyrex and the experiment was performed under a high vacuum, produced by a single stage all-metal, Gaede's Mercury steel diffusion pump which was kept continuously running during the course of observations. That the apparatus was vacuum tight was checked by leaving it under a vacuum for several days and taking occasional readings of the pressure inside, on a McLeod Gauge. The high voltage which was applied on the probe L was obtained from an Evershed High Tension D.C. Motor Generator set, M.

The electrical connections were made as shown in Fig. 1.

Theory of the Experiment, Results and Discussions.

(a) *Thermionic Emission.*

The plate current due to thermionic emission from a hot surface is limited by the presence of a negative space-charge very close to its surface. The potential distribution in a space between a plane positive plate and a negative hot plane surface, filled with a negative space-charge of high density, is not a linear function of the distance from any of the electrodes. Up to a small distance from the negative surface, the field is reversed and the potential at a point within this region has got a negative maximum value as shown at A in Fig. 2. The position of this maximum is, in general, independent of the

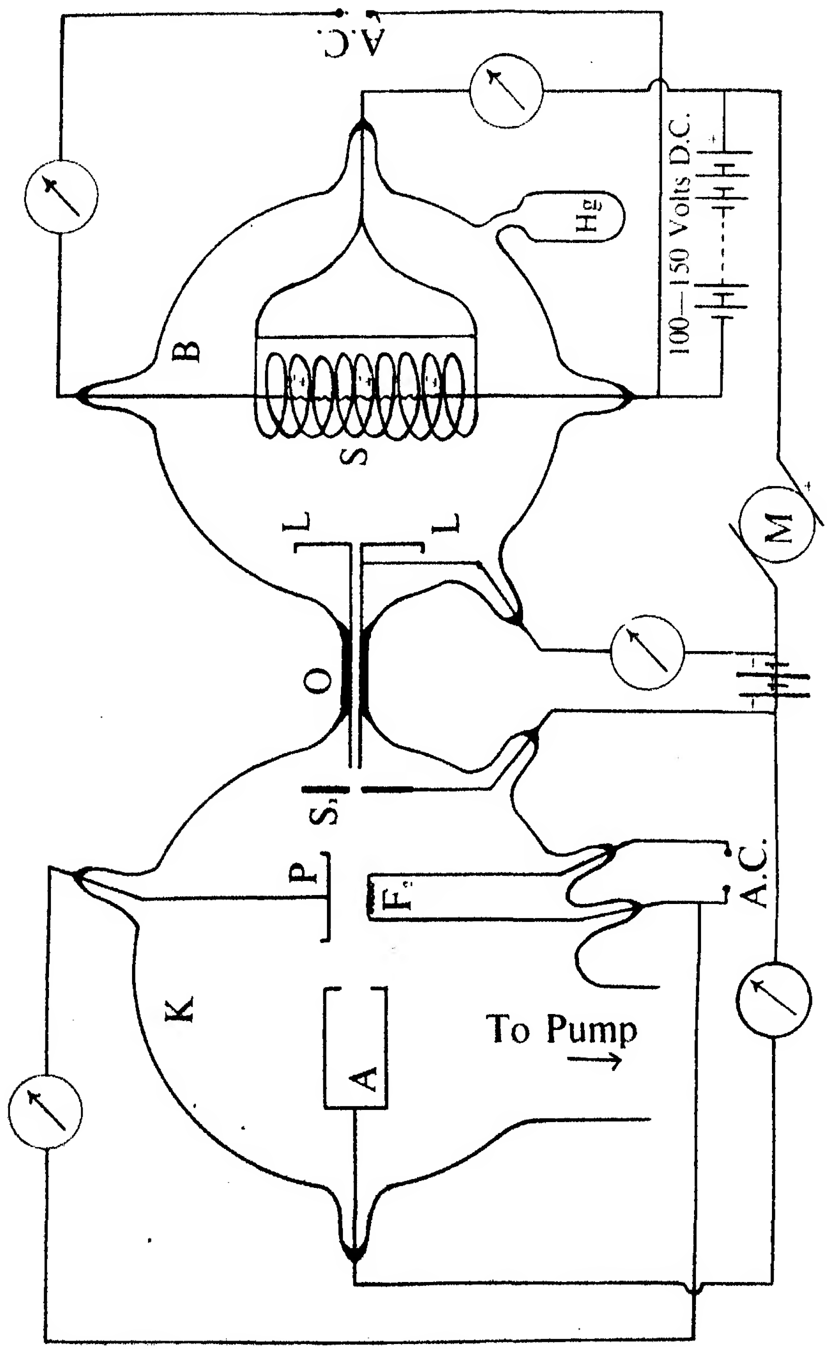


FIG. 1.

plate voltage, provided it is large enough compared with energy of the thermionic electrons. Under these conditions the plate current is independent of the temperature of the surface and is mainly controlled by the plate potential (Schottky, 1914). The plate current is given by the relation

$$i = \frac{V^{3/2}}{9\pi} \cdot \sqrt{\frac{2e}{m}} \cdot \frac{1}{d^2}$$

where V is the potential difference between the positive surface and the point A (Fig. 2), e and m are the electronic charge and mass respectively and d is the distance of the positive plate from the point A.

The majority of the electrons in the space-charge have low energies ranging from 0 to 1 volt and those for which this value is lower than the potential at A are reflected back to the hot surface. In fact, due to diffusion, the electrons possess random directions of motion in this region.

The thermionic emission from a hot surface is materially effected by the presence of vapours surrounding it but Mercury vapours and inert gases at low pressures are found to have no effect on thermionic emission from Tungsten (Langmuir, 1913).

The distance between the filament F_2 and the plate P is kept very small compared to the mean free path of the electrons in Mercury vapours at room temperature and therefore the probability of ionization of Hg vapours by thermionic electrons in the present experiments is extremely small. The presence of Mercury vapours in our apparatus, consequently, does not make the condition for the thermionic emission from F_2 very different from those which would exist in a high vacuum.

(*b*) *Production of the positive ions of Mercury.*

Langmuir and Mott-Smith (1924) have shown that if a plane electrode is immersed in the glow of an ionized gas and maintained at a potential lower than that of the gas, the positive ions move towards the electrode while the electrons move away from it. An excess of positive electricity accumulates near its surface to form a 'sheath' to it until it is strong enough to neutralize the effect of the negative electrification on the electrode. The field on the boundary of the sheath will be zero and the negative electrification on the electrode will have no effect outside this boundary. The phenomenon will be analogous to that of a cathode in a Normal Discharge of a gas at low pressure. There is a continuous flow of the positive ions from the ionized gas to the sheath and from there to the electrode. The current i to the electrode is given by the relation

$$i = \frac{enUA}{\sqrt{6\pi}} (1+L)$$

where A is the area of the sheath, n is the number of ions per unit volume of the ionized gas outside the sheath and U is the velocity of mean square of these

ions, L is the number of secondary electron produced by a single positive ion, and e is the electronic charge. In the case of Hg ions the value of L is very small and can be neglected as compared to unity (Langmuir and Mott-Smith, 1924).

The majority of the ions coming from the 'sheath' strike the electrode normally, with the energy corresponding to the difference of potential between the probe and the boundary of the sheath. If there is a hole in the electrode, the dimensions of the hole being small compared to those of the electrode, some ions will pass through it retaining their full energy.

The Mercury Arc was run at 100–150 volts D.C. and the electrons of the Arc had energy large enough to produce in Hg vapours, multiply charged ions, carrying as much as four positive charges (Bleakney, 1930). The number of the multiply charged ions is, however, small compared to the number of singly charged ions.

(c) *Effect on the Space-charge.*

The positive ions sweeping across the space-charge may remove the electrons from it or influence it in the following ways :—

1. The direct capture of free electrons of the space-charge, by fast Mercury ions.

2. The formation of negative ions of Mercury by attachment of the low velocity free electrons of the space-charge to the neutral Mercury atoms. The transfer of the electrons from the negative ions to the fast positive ions during the collision of the two ions.

3. The fast positive ions of Mercury may produce ionization by direct collision with Mercury atoms (Jones and Galloway, 1936). The slow positive ions produced from ionization may re-combine with the slow electrons of the space-charge, or they may accumulate round the surface of the negatively charged filament and neutralize the effect of the negative electrification of the space-charge.

4. The fast Mercury positive ions may get converted into fast neutral atoms, giving rise to slow positive ions, by a process known as 'Umladung or Electron Exchange' (Kallman and Rosen, 1930; Arnot and Marjorie, 1939). The fast neutral atoms and the slow positive ions resulting from this process may behave as given under 2 and 3.

(d) *Result and Discussion.*

A typical family of curves showing the relation between the plate current to P and the temperature of F_2 is given in Fig. 3. When observing the effect of the positive ions on the space-charge the plate current was adjusted at the horizontal part of the curve (Fig. 3) corresponding to the applied plate voltage.

Mercury ions of energy of 600–1,000 volts D.C. were fired into the space-charge. The positive ion current to the Langmuir probe L was increased

during observations to about one milliampere by putting the maximum current through the Mercury Arc. No measurable change was observed in the plate current when the positive ions beam was on.

The re-combination of ions and electrons has been known ever since their discovery was made in conducting gases. For example, the light from a glow

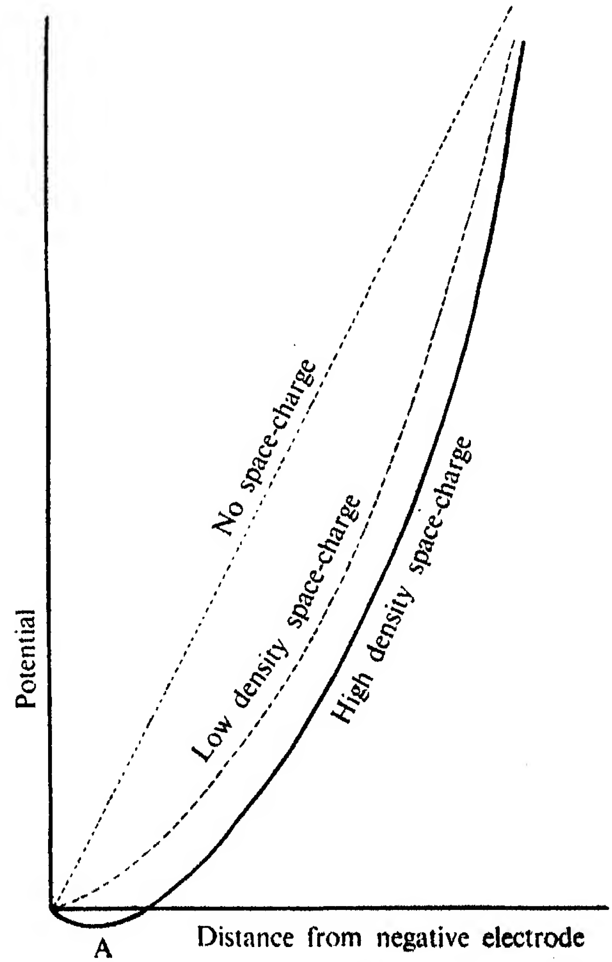


FIG. 2. Curves showing the effect of negative space-charge on the potential distribution between two parallel plane electrodes.

discharge in a rarified gas is attributed to the re-combination of ions and electrons. But the chances of re-combinations, which exist in a discharge tube, are very favourable, and it is difficult to reproduce them outside under controlled conditions. The velocity of electrons in an ionized gas varies from zero to any value upward depending upon the positive field applied on the gas. The

capture of an electron by a positive ion means that *the electron settles down* in one of the Bohr orbits of the atom, which will be possible only if the electron loses part of its initial energy. This can take place in two ways, either by radiation, when there is a direct capture of electron by positive ion, or by a collision with a third body, in which case the re-combination takes place in two successive steps. At first a negative ion is formed by the attachment of an electron with a neutral atom and afterwards the negative ion and a positive ion come in collision, in which the electron is transferred to the positive ion, releasing

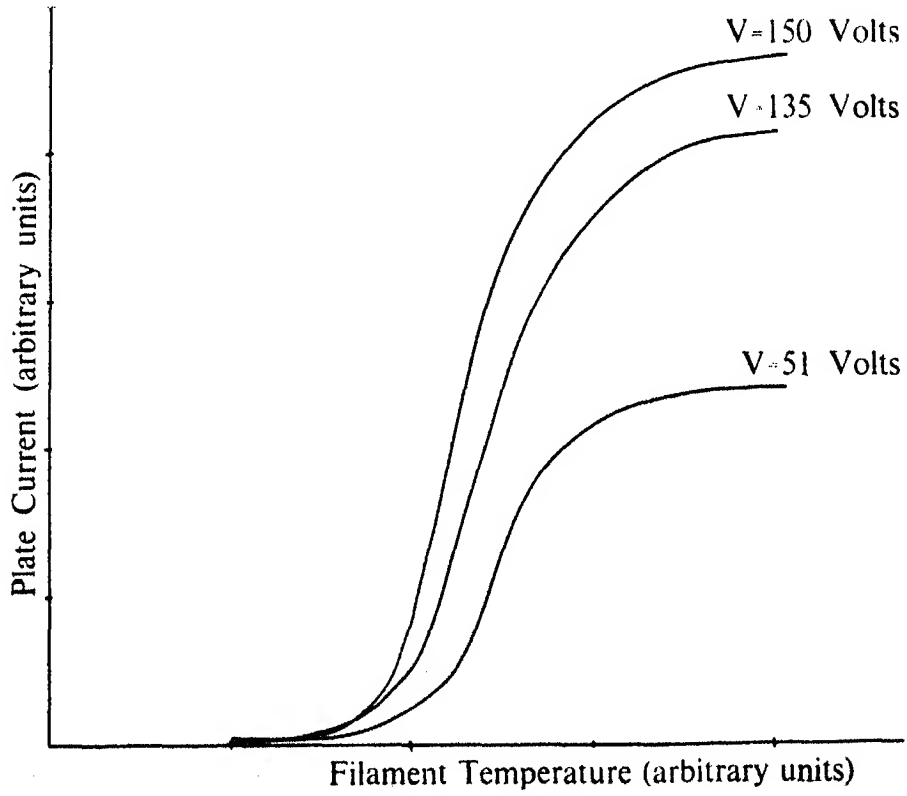


FIG. 3.

the neutral atom with its excess of energy. The probability of formation of negative ions varies enormously in different gases and in any particular vapours it depends upon its state of purity and other experimental conditions (Wahlin, 1922; Loeb, *Kinetic theory of gases*). It is difficult, therefore, to make an estimate from the data available of the probability of re-combination of ions by three body collision in any vapour.

The direct re-combination of positive ions and free electrons has also been studied by some experimenters.

Miss Dewey (1928) believes that this type of re-combination is very intense in the negative glow of a discharge. Investigations of Miss Hayner (1926) also show high probability of this process. Important information can be obtained from the work of Kenty (1928) in which it is shown that electrons of energies of 0 to ½ volt are captured by positive ions of Argon.

Mohler's (1928) experiments on the re-combination spectra of Cæsium and Helium show that the coefficient of re-combination depends upon the velocity of electrons. The probability of re-combination for 0·2 volt electrons has been shown to be much higher than for electrons of 1·4 volts energy.

The process of capture of electrons, both free and atom-bound, by fast positive ions has been studied by Rutherford (1930), and others (Henderson, 1922; Brigg, 1927). Rutherford has found that very swift Alpha particles from Radium are capable of capturing electrons from gas molecules and that the probability of capture is a function of the velocity of the Alpha particles.

Other investigators (Kallman and Rosen, 1930; Arnot and Marjorie, 1939; J. J. Thomson, 1921) show that fast positive ions, other than the Alpha particles, also capture electrons from gas molecules and atoms.

Davis and Barnes (1929) and Barnes (1929, 1930) have investigated the capture of free electrons by Alpha particles. A beam of Alpha particles from a Polonium source was shot in a stream of electrons, obtained from a hot cathode. The velocity of the electrons was controlled by placing a grid near the cathode. By maintaining a suitable density of electrons in the stream, it was found that the efficiency of capture of electrons by Alpha particles was as high as 100 per cent for specified velocities of the electrons but at other velocities its value was calculated to be small. The time of capture-collision between an Alpha particle and a free electron was estimated to be 3×10^{-10} seconds.

In the present experiments the density of electrons in the thermionic current was of the order of 10^8 electrons per cc. The density of Mercury ions near the Langmuir probe L in the Arc-chamber was estimated to be higher than the above value, but taking into consideration the fact that a large fraction of the ion current is neutralized while passing through the canal C, the density of ions in the ion beam in the chamber K would have at least a minimum value of the order of 10^5 ions per cc.

Under the conditions which exist in our experiment, it was considered probable, keeping in view the points discussed above, that the fast Mercury ions would influence the negative space-charge both directly and indirectly.

From the negative results of the experiment it appears that:—

(1) The efficiency of ionization of Hg vapours by fast positive ions of Mercury is small, which is in agreement with some experimental results (Jones and Galloway, 1936).

(2) The probability of the formation of negative ions by the attachment of free electrons to the neutral Mercury atom is either small or the collisions

between the negative ions and the positive ions of Mercury in which the electrons are transferred to the positive ions are not frequent.

(3) The capture-collisions between free electrons and Mercury positive ions are rare.

The results with different ion concentrations and various kinds of ions will be given in a subsequent paper.

We take this opportunity to record our thanks to the Hon'ble Dr. Sir S. M. Sulaiman, Vice-Chancellor, Muslim University, Aligarh, for a special grant which enabled the Department to equip the laboratory for High Vacuum work and for his keen interest and encouragement throughout.

We express our thanks also to Prof. A. B. A. Haleem, Pro-Vice-Chancellor, for having provided general facilities for carrying out this work.

REFERENCES.

Arnot and Marjorie, (1939). *Proc. Roy. Soc.*, **A169**, 437.
Barnes, (1929). *Phys. Rev.*, **34**, 1229; 1930. *Phys. Rev.*, **35**, 217.
Bleakney, (1930). *Phys. Rev.*, **35**, 139.
Brigg, (1927). *Proc. Roy. Soc.*, **A114**, 341.
Davis and Barnes, (1929). *Phys. Rev.*, **34**, 152.
Dewey, (1928). *Phys. Rev.*, **32**, 918.
Haynor, (1926). *Zeits. f. Phys.*, **35**, 365.
Henderson, (1922). *Proc. Roy. Soc.*, **A102**, 496.
Hertz, (1923). *Zeits. f. Phys.*, **18**, 307.
Jackson, (1927). *Phys. Rev.*, **28**, 524.
Jones and Galloway, (1936). *Nature*, **138**, 973.
Kallman and Rosen, (1930). *Zeits. f. Phys.*, **61**, 61.
Kenty, (1928). *Phys. Rev.*, **32**, 624.
Langmuir, (1913). *Phys. Rev.*, **11**, 450, 453.
Langmuir and Mott-Smith, (1924). *Gen. Electr. Rev.*, **27**, 538, 544.
Loeb, Kinetic theory of gases, pp. 507–515.
Mohler, (1928). *Phys. Rev.*, **31**, 187.
Oliphant, (1928). *Proc. Camb. Phil. Soc.*, **24**, 451.
Richardson, O. W., (1902). *Proc. Camb. Phil. Soc.*, **11**, 286.
Rutherford, Chadwick and Ellis, (1930). Radiations from Radioactive substances, p. 120.
Schottky, (1914). *Phys. Zeits.*, **15**, 526.
Thompson, J. J., (1921). Rays of Positive electricity and their chemical applications, p. 48.
Wahlin, (1922). *Phys. Rev.*, **19**, 173.

Twelfth Ordinary General Meeting.

The Twelfth Ordinary General Meeting of the National Institute of Sciences of India was held on the 25th and 26th August, 1939 in the hall of the Royal Asiatic Society of Bengal, 1 Park Street, Calcutta. In connection with the General Meeting a Symposium on 'Coal in India' was held which was organized by Dr. C. S. Fox on behalf of the Institute.

The following Fellows were present:—

Bt.-Col. R. N. Chopra, *President*, in the Chair.
Sir U. N. Brahmachari, *Vice-President* (on 25th only).
Prof. J. N. Mukherjee, *Additional Vice-President* (on 25th only).
Prof. M. N. Saha, *Additional Vice-President.*
Dr. B. S. Guha, *Honorary Treasurer.*
Prof. S. P. Agharkar, Dr. C. S. Fox } *Honorary Secretaries.*

Prof. G. Bose (on 25th only).
Dr. N. K. Bose (on 25th only).
Dr. H. Chaudhuri (on 25th only).
Dr. B. N. Chopra (on 25th only).
Dr. A. L. Coulson.
Prof. S. Datta (on 25th only).
Mr. E. R. Gee.
Prof. J. Ghosh (on 25th only).
Dr. S. L. Hora (on 25th only).
Prof. K. S. Krishnan (on 25th only).
Dr. M. S. Krishnan.
Dr. R. B. Lal (on 25th only).
Prof. S. K. Mitra.
Prof. P. Neogi (on 26th only).
Dr. H. Srinivasa Rao (on 25th only).
Dr. A. C. Ukil (on 25th only).

Besides the Fellows there were also present a number of visitors, who being closely associated with the Coal Industry of this country, keenly participated in the discussions.

1. The minutes of the Eleventh Ordinary General Meeting of the Institute, held on the 5th April 1939, were read and confirmed.

2. The following papers were read:—

(1) Absorption of Electromagnetic Waves in the Earth's Atmosphere. By R. R. Bajpai and K. B. Mathur. (Communicated by Prof. M. N. Saha.)

(2) Heat of Ionic Dissociation of the Chloride and Bromide of Rubidium. By B. N. Srivastava. (Communicated by Prof. M. N. Saha.)

(3) Absorption and Reflection of Radio Waves at Oblique Incidence and their relationship with Vertical Incidence Phenomena. By K. B. Mathur. (Communicated by Prof. M. N. Saha.)

(4) The Extension of the (O, O) Band of OD. By M. Ishaq. (Communicated by Prof. M. N. Saha.)

3. The following papers were also read and discussed in connection with the Symposium on 'Coal in India':—

(1) History of the development of the Coal Industry. By E. R. Gee.

(2) The History of Coal-mining in India. By E. R. Gee.

(3) The Geology of Indian Coal. By E. R. Gee.
(4) Indian Coal reserves. By M. S. Krishnan.
(5) India's position in the world as a Coal producer. By M. S. Krishnan.
(6) Conservation of Coal. By M. S. Krishnan.
(7) Coal in relation to Metallurgical operations. By Cyril S. Fox.
(8) Coal in relation to power. By Cyril S. Fox.
(9) Carbonization of Coal and recovery of by-products. By B. Wilson Haigh.
(10) Carbonization of Coal. By W. J. Savage.
(11) Fuel Oil from inferior Jharia Coals. By S. K. Roy and S. S. Ghosh.
(12) Briquetting of Coal in India. By C. Forrester.
(13) Briquetting of Coal. By A. N. Mukherjee.
(14) The underground Gasification of Coal. By Cyril S. Fox.
(15) Domestic Coke. By N. N. Chatterjee.
(16) Domestic Coke. By C. Forrester.
(17) Fuel Research. By N. N. Chatterjee.
(18) Fuel Research in India. By C. Forrester.
(19) Fuel Research: Indian Coal. By Cyril S. Fox.
(20) Safety in Mines through education. By H. K. Nag.
(21) Safety in Coal Mining. By E. B. Park.
(22) Safety in Coal Mining. By R. P. Sinha.
(23) Packing with incombustible material in Coal Mines. By L. J. Barraclough.
(24) Some physical conditions which affect spontaneous heating in Coal Mines. By W. Kirby.
(25) Fires and Ignition in Mines. By E. B. Park.
(26) Storage of Coal. By C. Forrester.
(27) Storage of Coal. By E. R. Gee.
(28) Indian export trade in Coal. By C. A. Innes.
(29) The marketing of Coal in India. By C. A. Innes.
(30) Some problems of Indian Coal. By A. L. Ojha.
(31) Chemical constitution of Coal. By N. N. Chatterjee.
(32) Methods of analysis of Coal. By N. N. Chatterjee.
(33) Methods of analysis of Coal in India. By C. Forrester.
(34) Sampling of Coal. By J. S. Sanjana.
(35) Coal cleaning and beneficiation in India. By C. Forrester.
(36) Coal cleaning and beneficiation. By E. R. Gee.
(37) Sulphur in Coal. By N. N. Chatterjee.
(38) Moisture in Coal. By E. R. Gee.
(39) Moisture in Coal. By J. S. Sanjana.
(40) A Critical Study of some Indian Coal Ashes. By R. K. Dutta Roy.
(41) Ash in Coal. By J. S. Sanjana.
(42) Volatile matter in Coal. By C. Forrester.

(43) Classification of Coal. By M. S. Krishnan.
(44) Micro-structure of some Indian fusains. By N. N. Chatterjee.
(45) Microscopic determination of the Barakar and Raniganj sandstones of the Jharia Coalfield. By S. K. Roy.
(46) Studies in Coal by X-ray diffraction methods. By C. Mahadevan.
(47) Studies on the action of solvents on Indian Coal. By R. K. Dutta Roy.
(48) The Palæobotanical correlation of Coal seams in India. By B. Sahni.
(49) State control in the Coal Industry. By M. S. Krishnan.
(50) Present status of the Coal Industry. By J. K. Dholakia.
(51) Present status of the Coal Industry. By D. D. Thacker.

4. The Fellows and visitors were entertained to lunch and tea on the 25th August, 1939 through the generosity of the leading Coal Mining Companies of Calcutta.

The proceedings of the Symposium will be published in the *Proceedings* of the Institute in due course.

With a vote of thanks to the chair the proceedings terminated.

INDEX

INDEX

INDEX